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C. 1

CORROSION CONTROL FOR MANNED SPACE FLIGHT NETWORK FACILITIES

by Herbert J. Gall

Prepared by
BENDIX FIELD ENGINEERING CORPORATION
Owings Mills, Md.
for Goddard Space Flight Center

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ERRATA SHEETS

for

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CORROSION CONTROL

for

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FACILITIES

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Errata List

Cover Page: In address line, "Owings Mills, Md." should read,
     "Columbia, Md."

Title Page: In address line, "Owings Mills, Md." should read,
     "Columbia, Md."

Page x: 1st column, first acknowledgement; Alva E. Smith, Head
     should read, Alva E. Smith, Head*(the footnote for the
     asterisk should read, *Deceased).

Page x: 1st column, 6 acknowledgement which reads, National
     Paint, Lacquer and Varnish Association, Inc. should read,
     National Paint, Varnish and Lacquer Association, Inc.

Page x: 1st column, change "John Deason" to read: "John Daesen."

Page x: 1st column, change "Palmerton, New Jersey" to read:
     "Palmerton, Pennsylvania."

Page x: 2nd column, first acknowledgement should read:
     Ralph W. Mollerick
     Aerospace Technologist
     Engineering Support Section
     Engineering Support Branch
     Manned Flight Engineering Division

Page x: 2nd column, 8th acknowledgement, James B. Horton should
     read, Dr. James B. Horton

Page xi: Column 2 change "Walter Showak" to read: "Dr. Walter
     Showak"

Page 1-3: Column 2, 8th line up from bottom reads, "ing a thin
     layer of almost pure aluminum" should read, "ing a thin
     layer of more anodic aluminum"

Page 2-3: In Table 2-1. Electromotive Series, the notes:
"*Oxidation reaction voltages
✝+indicates valences"

should read:

"✝Oxidation reaction voltages
 *Indicates valences"

Page 2-23: Second column, eighth line from the bottom which
reads, "pensive life-cost method. Not point D at 3 years"
should read, "pensive life-cost method. Note point D at
3 years"

Page 3-2: Column 1 "Cast Aluminum Alloy Designations" should
read, "Cast Aluminum Alloy Designations See special note
re: Cast Aluminum page G-6."

Page 3-4: Table 3-1: Column 5357-6 should read, 5457-0.

Page 3-5: Right hand column, paragraph g(1) which reads,
"Exfoliation corrosion occurs principally in extruded
sections and follows" should read, "Exfoliation corrosion
occurs principally in sheet and plate and follows"

Page 3-7: First column, paragraphs "h., i., j." should read,
"c., d., e."

Page 3-7: The line before paragraph 3.8 which reads, "cussion
on emf computations, page 2-4". should read, "cussion on
emf computations, page 2-3".

Page 3-7: Right hand column, paragraph b which reads, "metal
clad the surface with high purity aluminum; high purity
aluminum is extremely corrosion resistant and is anodic to
the base metal."; should read, "metal clad the surface with
higher potential aluminum; the aluminum will then be anodic
to the base metal."

Page 3-21: Paragraph 3.22, subparagraph c. which reads, "Are
alloys in solid solution" should read, "Are alloys in solid
solution (Annealed)."

Page 3-21: Paragraph 3.23.1, subparagraph g. which reads, "AISI type 410 when heat treated has the following results:" should read, "AISI type 410 when heat treated has the following strengths:"

Page 3-21: Column 2, second line which reads, "within several months in a hard environment" should read, "within several months in a harsh environment."

Page 3-21: Paragraph 3.23.2, subparagraph b. which reads, "Contain 14 to 27 percent chromium" should read, "Contain 12 to 27 percent chromium."

Page 3-22: In Table 3-11. under column heading "Corrosion Notes," line which reads, "Good corrosion-resistant surface is obtained by polishing and dipping in a 15% H_2NO_3 solution followed by a good water wash" should read, "Good corrosion-resistant surface is obtained by polishing and dipping in a 15% HNO_3 solution followed by a good water wash."

Page 3-24: In Table 3-12. line below headings which reads, "Martensitic (hardening)" should read, "Martensitic (hardenable by heat treatment)"

Page 3-24: In Table 3-12. fourth note down under General Guide Notes which reads, "Most readily machinable of all stainless steels, inferior to 430F in" should read, "Most readily machinable of all the martensitics, inferior to 430F in"

Page 3-25: In Table 3-12. line below headings which reads, "Austenitic" should read, "Austenitic (hardenable by cold work)"

Page 3-27: Paragraph 3.23.3, subparagraph a. which reads, "Are in two AISI groups: the 200 series and the 300 series. The 200 series is essentially Cr, Nr, and Mn;" should read, "Are in two AISI groups: the 200 series and the 300 series. The 200 series is essentially Cr, Ni, and Mn;"

Page 3-27: Column 2, 5th line from bottom which reads "And once an electrode is provided, the oxidizing" should read, "And once an electrolyte is provided, the oxidizing."

Page 4-7: Paragraph 4.9, the fifth line reads, "other mechanical devices. As such times the cor-" should read, "other mechanical devices. At such times the cor-"

Page 4-14: Paragraph 4.14.2.2, subparagraph d. last word is badly printed, should read, "Epoxy resins. Outstanding chemical resistance."

Page 4-26: Table 4-17: under heading, Intermediate If Required, third block down which reads, "TT-PP-102[5]. Class B." should read, "TT-P-102[5]. Class B."

Page 4-32: Specification MIL-E-7729: Lines which read, "Dry: set to touch in 30 minutes, dust free in two hours, full hardness in 48 hours
Brushing properties: satisfactory, flash point under 80°F.
Spraying properties: satisfactory, flash point under 80°F.

should read,

"Dry: set to touch in 30 minutes, dust free in 2 hours, full hardness in 48 hours. Flash point not under 80°F.
Brushing properties: satisfactory
Spraying properties: satisfactory

Page 4-39: Second column, fourth line, which reads, "tion, the action of the H_3PO_4 on the old paper may" should read, "tion, the action of the H_3PO_4 on the old paint may"

Page 4-46: In paragraph 10.3.1, line which reads, "within 8 hours after blasting if the relative" should read, "within 24 hours after blasting if the relative."

Page A-1: Column 2, third reference down; E. M. Reinhart should read, F. M. Reinhart.

Page A-2: Left column, 11th reference line which reads, National Paint, Lacquer & Varnish Association, Inc. should read, National Paint, Varnish & Lacquer Association, Inc.

Page A-3/A-4: Left column, 6th reference which reads, U.S. Steel Corp. should read, Aluminum Company of America.

Page G-1: The definition of Aeration which reads, "A wind-carried moisture-saline combination. (The 30-foot Apollo dish at Bermuda has 1 to 15 aerations perday, 365 days per year)" should read, "A wind-carried moisture-saline combination. (The 30-foot Apollo dish at Bermuda has 1 to 15 aerations per day, roughly 265 days per year)"

Page G-3: The definition of Huey Test which reads, "A laboratory test subjecting samples of stainless steel to boiling 65 percent nitric acid to check for transgranular and inter-granular corrosion." should read, "A laboratory test subjecting samples of stainless steel to boiling 65 percent nitric acid to check for intergranular corrosion."

Page G-3: The definition non-uniform phase delay; which reads, "Unequal time delay: of portions of the incident wave front caused by" should read, "Unequal time delay of portions of the incident wave front is caused by"

Page G-4: The Glossary term, "Polymide" is mispelled and should read, "Polyamide"

Page G-5/G-6: Move G6 to next page

Page G-6: Blank; should read as follows:

Cast Aluminum Alloy Designations

In February 1970, the Aluminum Association adopted a new system to designate cast aluminums. It will replace the one on page 3-2 as usage, and experience accumulate.

CORROSION CONTROL FOR MANNED SPACE

FLIGHT NETWORK FACILITIES

By Herbert J. Gall

Distribution of this report is provided in the interest of
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Prepared under Contract No. NAS 5-10750 by
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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

SUMMARY

The purpose of this study is stated in the title: *Corrosion Control.* Corrosion is an ever-present, complex force; there is no low-cost or simple short-range corrosion-control program that fits the MSFN station needs. The cost of the MSFN corrosion-control program must be related to the cost of the structures involved in order to bring the economics into focus. Because of the high-value structures and mission demands there are continuous savings and network capability upgradings that can be achieved simultaneously with proper corrosion control.

The corrosion problems at the MSFN stations are electrochemical in nature and have been explored in depth during the background investigation for this writing. Using the corrosion circuitry knowledge, the combative techniques, and the materials suggested herein, MSFN station personnel will be able to achieve a much higher degree of corrosion control.

The level of corrosion-control activity required at each station must be based on the severity of that station's environment. Therefore, four quantitatively-defined environments which include the entire range of the MSFN station environments were formulated. Basing the level of corrosion control on these defined environments permits a level of response commensurate with the severity of the cause.

CONTENTS

CONTENTS (cont.)

CONTENTS (cont.)

CONTENTS (cont.)

ILLUSTRATIONS

TABLES

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For their interest, guidance, and support during this study; sincere appreciation to:

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Frontispiece.   Corrosion Impact

CORROSION CONTROL FOR THE MANNED
SPACE FLIGHT NETWORK TRACKING FACILITIES

INTRODUCTION

GENERAL

The most formidable challenge confronting a long-range corrosion control program is proper communication. The reasons for communication difficulties are obvious. Corrosion is not dramatic. It takes place relatively slowly; therefore, corrosion seldom reaches a panic stage. When corrosion affects operational capability, money is made available for speedy correction. No one is held accountable for estimating the cost. Finally, a corrosion control program must extend over a period of 5 to 10 years in order to include the concept, planning, construction, and operational lifetimes of the facilities. The leading corrosion scientists and engineers estimate that the current, direct annual cost of corrosion to industry and homes in the United States ranges between $6.5 billion and $10 billion. When the indirect costs are added, the estimates jump to $15 billion. An accurate forecast of the cost of uncontrolled corrosion for the next 10 years at the MSFN tracking station facilities is presently impossible because of the lack of data. However, experience indicates that if corrosion is not brought under control, repairs and replacements could reach $350,000 per year in the MSFN. The techniques to achieve corrosion control at the MSFN stations are detailed in this work. Management always has several options that will apparently bring the problem under economical control; the selection of the proper option and the details of the followthrough are proposed to management in this work.

TECHNICAL

To achieve an acceptable level of control requires a wide variety of refined actions in both the design and maintenance of a facility. One primary decision necessary to this study was the selection of a common denominator that allows for the recognition, diagnosis, and solution of the corrosion problems at the MSFN tracking stations. Such a common denominator had to be inclusive enough to permit proper action but not detailed to the point of being ineffective. The author selected environment as the common denominator because environment determines the corrosion rate of any material or material combination. The total range of MSFN tracking station environments is divided into four types: dry, normal, humid, and harsh. The environment of any existing or future MSFN facility will fall within one of the above four types.* Identifying the environment of the MSFN station is the first requirement for using the data in this study. The data specify the metals, surface preparations, paints, platings, etc., to control corrosion in each of the four environments. Because of the complex nature of corrosion, there are no easy or simple solutions. The data in this study will aid the engineer and technician in understanding and using modern corrosion control techniques effectively.

* The four MSFN tracking station environments are quantitatively defined in paragraph 2.10 and table 2-4.

CHAPTER I. THE VARIOUS OPTIONS TO CONTROL CORROSION AT THE MANNED SPACE FLIGHT NETWORK TRACKING FACILITIES

INTRODUCTION

1.1 GENERAL

Rust comes in many forms, all destructive, and is not a new problem. During the Blue Nile campaign in Egypt, Seneca, general of the Roman army, reported to Rome that the pentlehooks on the Romans' new super crossbows were breaking because of corrosion and causing more casualties among the crews than the enemy was causing. Today's management faces reports from the field that are quite similar to that from the Blue Nile campaign. However, we now have preventive and corrective methods available that will achieve any degree of corrosion control desired.

One part of General Seneca's corrosion story and the MSFN tracking station corrosion story is identical: the need of a unified management and technical attack on the problem if any lasting success is to be achieved. Chapter I defines some of the technical problems and tools of a corrosion control program.

1.2 TECHNICAL

Chapter I serves primarily as a resume for the administrators and managers who must become involved in any proper attempt at corrosion control. Many engineers and technicans recognize the need for detailed, long-ranged corrosion control programs, but they have not communicated these needs to management. Better communications between the engineers and management must be established by the engineers. The engineer can use this study as a guide and communicate the corrosion problems and his recommendations to management by formal briefings and engineering memoranda.

PART A. ENGINEERING AND ECONOMICS OF THE MSFN CORROSION PROBLEM

There are many forms of corrosion which have been studied in great detail by corrosion engineers, researchers, and scientists. One form is known as electrochemical corrosion; it is this form that plagues the MSFN tracking station antennas. The electrochemical form of corrosion includes many varieties of corrosion and many types of each variety. The galvanic variety has dozens of types because any dissimilar metals, properly coupled and supplied with an electrolyte, will corrode at the anode of the couple. The rates of corrosion in any galvanic couple are determined by many different factors: separation of the metals in the galvanic series, the type of electrolyte, and the temperature. Chapter II describes the types of electrochemical corrosion that have occurred or can possibly occur at the tracking stations. Industrial researchers have developed techniques that will satisfactorily control the corrosion rates experienced at any of the MSFN tracking stations, and it appears that a proper and timely application of these techniques would be of much benefit; however, in many instances, corrosion control is emphasized only when rust becomes visible.

A corrosion engineer should be involved in the very early stages of procurement of any antenna. His initial action should be a study of the environment in which the facility will operate. This study must be completed and the recommendations submitted in the very early stages of design (before the preliminary plans are 20 to 25 percent completed). This early involvement of the corrosion engineer is the key to corrosion control. It is the environment that determines the corrosion rates, and a detailed knowledge of the corrosion rates enables the engineer to recommend what structural metals, surface preparation, and protective coatings are required to achieve various levels of control. An excellent time for management to check the corrosion control required for any proposed construction is at the 20 to 25 percent completion

point of the preliminary plans. At that time, a corrosion control briefing, which will include estimated costs for the total corrosion-control program, can be requested from the engineer who made the study. The corrosion engineer is also an excellent choice for the quality control team involved with the design, fabrication, and erection phases.

Regardless of the environment, there are technical options with their various economic impacts that can be selected to achieve various levels of corrosion control. The requirements for funds and manpower to provide corrosion control vary according to the hostility of the environment. A harsh environment* will necessitate a much greater manpower effort and expenditure of funds to control corrosion than a dry environment. A manpower ratio of 100 to 1 (harsh to dry) is not unrealistic. It is important that the true cost of corrosion control be understood. This cost is often distorted because of the expensive repair work made necessary by corrosion. However, expensive repair work is not the cost of control; it is the price paid for the lack of control. One difficulty in achieving corrosion control is providing funds and manpower within a suitable time frame. Another difficulty is selling a control program that spans the time from initiation of design to retirement of the facility. The cost of the features designed into the facility and the projected cost of the corrosion-control efforts during the lifetime of the structure should be considered as a lump sum rather than initial cost and operating cost. The attention paid to future corrosion problems during design and construction is much less costly than after-the-fact correction.

The relative costs of corrosion control and corrosion cure cannot be better described than by an

* Refer to table 2-4.

old adage, "An ounce of prevention is worth a pound of cure." The author has had many occasions to note that $10 worth of corrosion prevention would have saved $500 repair costs. This can be dramatically illustrated by a favorite tool of the economists, the qualitative plot. Figure 1-1* illustrates four different lifetime costs of corrosion control, any one of which could be selected for an antenna that is to be placed in a certain environment. The plot shows effort "A" with a low initial cost, a very high maintenance cost, and the programmed life of the antenna unobtainable. Effort "B" shows a higher initial cost, a reduced maintenance cost, and the programmed life obtainable. Effort "C" shows a still higher initial cost, a much reduced maintenance cost, and an extended programmed life. Note that the programmed life costs of corrosion control of efforts "B" and "C" are equal. However, the lifetime maintenance cost of effort "B" is much higher than effort "C." This means more frequent maintenance on "B" would require more downtime and more mission capability degradation. The original effort "D" illustrates a very high initial cost with a very low maintenance cost and a long antenna life with minimum antenna mission capability degradations.

A study of the cost of corrosion control of any complex structure (an antenna) in a designated environment can be quite revealing. With so many variations in costs, capabilities, and lifetimes, it is obvious that there are a variety of possibilities for controlling corrosion. This chapter is a condensation of the study stressing the manager's interest and the various options for controlling corrosion that are available to MSFN management.

* Figure 1-1 does have an inherent blind spot; it does not show mission capability degradation during maintenance periods.

PART B.   THE CORROSION RESISTANCE OF METALS

1.3   GENERAL

In controlling corrosion, the proper use and combination of uses of various metals exert a great influence in determining corrosion rates. Significant variations in corrosion rates occur among structural metals and alloys when subjected to the same environment. The corrosion control capabilities of the structural metal family may show variations of as much as 30 magnitudes. It is because of such differentials in performance that it is necessary to consider several of the principal metals used at the MSFN tracking stations:

aluminum, iron, mild steel, stainless steel, magnesium, and nickel.

1.4   METALS AT THE TRACKING STATIONS

1.4.1   ALUMINUM

The purer the aluminum, the greater is its resistance to corrosion. The corrosion problem with aluminum arises because the aluminum must be alloyed with other metals such as copper or zinc to obtain the necessary high-strength properties; this increases susceptibility to corrosion. The cor-

INITIAL COST OF
CORROSION CONTROL
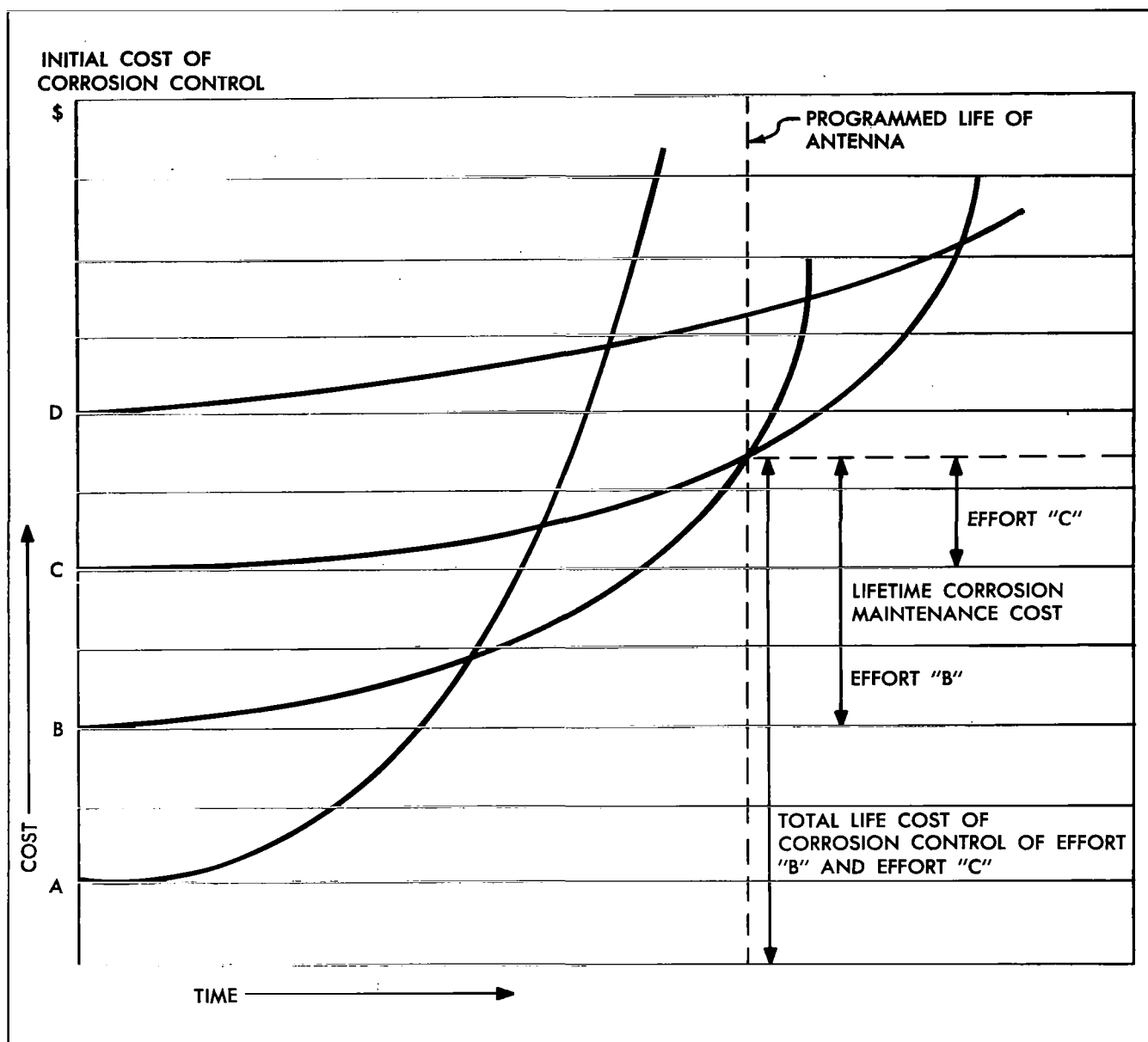
Figure 1-1. Life Cost of Corrosion Control

rosion resistance of aluminum results from a nat-
urally formed oxide film. The tendency of alumi-
num to form a protective oxide is exploited in
artificially applied protective coatings. Anodizing
is one process that provides such an oxide on the
aluminum. The high corrosion resistance of pure
aluminum has resulted also in its use as a surface
barrier treatment for structural metals. The fol-
lowing are examples:

    a. Metallizing (flame spraying) with 99 per-
       cent pure aluminum establishes an effec-
       tive barrier against corrosion of the steel
       substrate.

    b. Electroplating with aluminum is another

coating technique; however, the coating is
quite thin.

    c. Cladding is a common method for protect-
       ing high-strength aluminum alloys. The
       technique consists of mechanically apply-
       ing a thin layer of almost pure aluminum
       over the surface of a high-strength alumi-
       num alloy.

    The more extensive use of aluminum for struc-
tural members should be encouraged. In many
structures, the weight-to-strength ratio is attrac-
tive when the designer can reduce foundation and
structural costs because of lighter loads. The ten-

sile and yield strengths of the aluminum alloys and the high anodic position of aluminum in the electromotive series have undoubtedly restricted its use; however, when properly used, aluminum offers many advantages. A 30-foot antenna designed initially to be structured entirely of aluminum and covered by a radome is a configuration well worth investigation. Chapter III, Part A describes the metallurgical, structural, and corrosion properties of aluminum in some detail. It also compares the various aluminum alloys.

1.4.2 IRONS AND STEELS

Because of their high yield and tensile strengths, machinability, and acceptance of many types of corrosion protection in the form of coatings, platings, and treatments, iron and steel compositions will continue as the mainstay of large and complex structures for the foreseeable future. The low-alloy ferrous metal compositions are vulnerable to corrosion; the high-alloy steel compositions are more corrosion resistant and more expensive. Paint coating systems are relatively inexpensive, and often have limited service life. Sealed, flame-sprayed aluminum and zinc coatings are excellent corrosion barriers, but their application cost is higher than paint coatings. The choice of a coating system is always a compromise; the compromise is dictated by the price the buyer is willing to pay to control corrosion for a specified period of time for a specific function in a given environment. Such a compromise should never be made without extensive study because the cost can be high should a poor choice be made.

The means for controlling corrosion on iron and steel are numerous, and the final selection should be made by management after a presentation of alternatives, potential performances, and costs. A proper study to reveal the best, least-cost method always considers the total corrosion-control cost during the proposed life of the structure. A least-cost method predicted only on initial cost ignores all of the consequences of environmental and functional impacts. Chapter III, Part B describes the various types of ferrous metals and options for controlling corrosion on these metals.

1.4.3 MAGNESIUM

Magnesium is quite similar to aluminum. It is a light metal which has a high strength-to-weight ratio and good stiffness characteristics. The metal in the pure state is seldom used for structures. Magnesium alloys perform acceptably in dry environments, but a saline or salt water contaminated atmosphere greatly accelerates corrosion. Magnesium alloys resist alkalies, but all mineral acids except hydrofluoric and chromic acids will attack magnesium rapidly. Magnesium usage in

normal, humid, and harsh environments is not recommended for two reasons: (1) it has poor resistance to a saline attack, which is usually present to some degree, and (2) the position of magnesium in the galvanic series often leads to early sacrificial failure because magnesium is anodic to all structural metals in most electrolytes. The galvanic activities can be prevented by isolating the magnesium from the other metals; however, isolation may not be economically possible. The corrosion of magnesium in the MSFN tracking station facilities, as on electrical connectors, can be extremely rapid. The rate of corrosion attack on magnesium in a harsh atmosphere may reduce the total life of such connectors to 6 months.

Corrosion of magnesium can be controlled to some degree by proper use, special finishes, and environmental sealing. Magnesium resists stress corrosion because the magnesium grain boundaries are cathodic to the grains, and the boundaries are thus protected. Magnesium alloys require good design, good finishing, and proper installation. The proper use of magnesium requires a recognition of the potential corrosion susceptibility of the material. In the manufacture of magnesium-containing assemblies, the corrosion potential must be countered; magnesium parts must be accessible for inspection and capable of receiving the necessary corrosion treatment after manufacture. Normally, magnesium alloys are protected by chemical or electrochemical treatments which oxidize the surface into a more stable form. The chemical or anodic treatments must be further protected by painting with a relatively impervious organic film. The chemical treatment prior to painting increases the resistance to corrosion; it also prevents the formation of an alkaline surface under the coating which would cause very rapid deterioration of the paint. Because of its high propensity to corrode, the use of magnesium in noncontrolled natural type environments (without radome cover) should be studied with much care. Chapter III, Part C describes the characteristics of magnesium in a manner that will assist the corrosion-oriented engineer to place it in proper perspective for use in the MSFN tracking facilities.

1.4.4 NICKEL

The element nickel, alloyed with ferrous metals and chromium in the proper percentages, gives outstanding corrosion resistance. Nickel will alloy with so many other metals and in so many composition percentages that there are thousands of variations in use as decorative and structural metals. Nickel can be plated on ferrous metals to meet almost any functional demand. One deficiency of nickel concerning corrosion control is

that it does not provide cathodic protection when used as plating on ferrous metal. The use of high-nickel alloys for certain structural parts is expensive and, if viewed only as an initial cost impact, cannot compete with other metals. However, it is competitive when costed over the projected lifetime of the facility for certain parts of the antenna. This is especially true if the antenna is used in a harsh environment. Just how many bits and pieces of antenna would show a decreased corrosion-control cost if fabricated from nickel alloys is unknown at this time, but it could be determined. It is sufficient to say that nickel has enormous corrosion-control potential. If projected antennas include a corrosion study, the engineer would undoubtedly recommend high-nickel alloys for certain areas to minimize lifetime corrosion cost and downtime. Chapter III, Part D explains many features of nickel and its alloys.

1.4.5 STAINLESS STEELS

Stainless steels are compositions containing iron and chromium, or iron, chromium, and nickel with minor amounts of other elements. Although many stainless steel compositions display excel-lent corrosion resistance in a variety of environments, not all stainless steel alloys resist corrosion to the same degree in all environments. There is an option of many stainless steel alloys. The final choice should be made with much care after a detailed matching of the environmental and structural impacts with the response characteristics of the appropriate stainless steel options. The initial cost of high-alloy steels compared to the low-alloy steels is high. Inclusion of the expensive alloying elements such as chromium, nickel, and molybdenum is responsible for the high cost. To be classed as stainless steel, the alloy must contain a minimum of 11 percent of chromium. Some stainless steels contain as much as 18 percent chromium, 12 percent nickel, and 2 percent molybdenum. The corrosion resistance of this group of stainless structural metals results from a natural tendency to form an extremely thin oxide film when exposed to air. The film resists further corrosion. There are many parts of the MSFN tracking station antennas that would readily lend themselves to stainless steel composition. Panel adjustment bolts, gusset plates, and base plates are several examples. Chapter III, Part E looks at the metallurgy and corrosion resistance of stainless steels.

PART C. PROTECTIVE COATINGS (PAINTS)

A very effective method of controlling corrosion is to shield the metals in a manner that will not allow the electrolyte to make contact with them; with no electrolyte, there is no ionization, no flow of electrons, and no corrosion. The most widely used shielding material is paint. The proper paint, properly applied to a properly prepared substrate, is an excellent corrosion barrier; however, the true lifespan of many paints is never realized because of inadequate surface preparation and poor craftsmanship.

The task of protecting antennas against corrosion by using paints for protective coatings is quite involved. The proper substrate preparation has many complicated requirements, such as adhering to maximum time intervals during which clean bare metals may be exposed before they are painted. Also, during the sandblasting process, there are problems of sand contamination, grain cut, velocity, and volume. The variety of complex paints available with their special uses, restrictions, incompatibilities, and electrical and mechanical properties requires careful study before selection. There are adhesion tests, alkaline tests, and thickness tests that must be performed to ensure a high quality end product. The application techniques of many epoxies, vinyl resins, and zinc-rich silicates are very exacting. The combinations of surface preparations, paints, and application techniques are almost unlimited, but only a very few will perform economically and as required in a specific environment and function. The success of protective paint coatings depends on selection of the proper combination. The environment offers the maximum number of indicators that point to the proper combination. Table 2-5 shows that different environments can affect corrosion rates in multiples of 2000. Chapter IV examines the paint coating system by discussing flaws in structural metals, surface preparation techniques, various paint binders, and various groups of primer and top coat combinations that constitute paint systems for the four environments* in which the MSFN antennas are placed. The paint systems are listed by federal and military specification number. In conclusion, Chapter IV provides a detailed set of contract specifications for repair painting an X-Y axes antenna.

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* Because environments play the major role in determining corrosion rates, four separate environments that include all the MSFN tracking station environments have been quantitatively defined in table 2-4.

PART D. SURFACE TREATMENTS FOR CORROSION CONTROL

With the exception of ferrous metals with a high content of chromium and nickel and certain nearly pure metals, surface treatment to control corrosion is mandatory. The variety of the surface treatments is extensive and encompasses many techniques. The purpose of the coatings is to shield the base metal from the environment. The coatings can be applied by hot dipping, electroplating, cladding, flame spraying, anodizing, etc. The coating material can be metallic, such as zinc or aluminum, or it can be an oxide coating created by the anodizing process. The determination of the proper surface treatment for corrosion

control should be made only after full consideration is given to the environment, the base metal involved, the functional role to be played, and the proposed lifetime of the structure. Here again, as with all decisions regarding corrosion control, the correct surface treatment for a given set of circumstances can be ensured only after a proper study. Without a thorough understanding of each of the contributing factors, the control of corrosion may not be at the level desired, regardless of the money spent. Chapter V outlines many of the surface treatments used for corrosion control on structures.

PART E. RADOMES

The use of radomes on certain antennas has been studied in great detail and from practically every known angle. Many of the studies can be applied to the MSFN tracking station antennas. The radome does one job: it creates a controlled environment in which the effects of winds, thermal distortions, and corrosion can be almost eliminated. A radome cover degrades the antenna's electrical characteristics. The amount of degradation for different types of radomes varies a great deal. For example, in a heavy rain, the noise level increase caused by an air-supported radome may be as much as 80°K; the noise level increase caused by a metal space frame radome in the same rain may amount to 10°K. Following the rainfall, the noise level of the space frame radome decreases very rapidly; the air-inflated type may retain the high noise level for much longer periods of time. The use of a radome amounts to a compromise between the electronic and the facility engineers.

It seems that one consideration has been overlooked in the studies regarding the possibility of high winds existing during a critical mission. There must be a crossover point when the distortion of the antenna caused by increasing winds is more degrading to the electronic performance than the maximum degradation caused by a good radome. If, for example, gusting winds at 40 knots would render a given level of degradation, and

the maximum degradation caused by a radome would be somewhat less than this, then the radome offers an electronic advantage beyond this 40-knot crossover point. The advantage exists for any wind velocity from the crossover point to the wind velocity design limits of the radome. The advantage may be even greater because the personnel would train with a constant and known electronic degradation caused by the radome and not be confronted with random problems caused by high winds. This training might well offset some of the electronic disadvantages of the radomes. The answer could be determined for any antenna location by a study considering the total degradation caused by the radome and the statistical probability of weather conditions that would create a similar or greater degradation.

Placing a radome over an antenna which was not designed to be so protected is much more expensive than using an integrated antenna-radome design. It is also true that the larger the antenna, the less costly the radome becomes because of structural savings possible on the antenna. The prices of different types of radomes vary greatly. The price of radomes for a 30-foot antenna ranges up to $150,000; for an 85-foot antenna, the price ranges up to $450,000. Chapter VI describes the rigid and air-inflatable types of radomes and lists their advantages and disadvantages in some detail.

PART F. THE MSFN CORROSION EVALUATION AND TEST AREA

Due to the harsh environments surrounding many of the MSFN antennas, all structural and equipment metals and alloys are under a very aggressive and continuous corrosion attack. Selection of the proper metals, alloys, protective coating systems, and metallic treatments can result in a great dollar saving and an upgraded mission status. In order to determine the best selection, testing is necessary. With the goal of gaining more control of corrosion and reducing maintenance costs, the MSFN is running project CETA on Coopers Island in Bermuda. Project CETA, Corrosion Evaluation and Test Area, has hundreds of paint systems, structural metals, specimens of welds, wire cables, etc., under test in the very harsh, seacoast environment. All known paint systems, galvanic couples, welds, cables, and metals in use at the tracking stations are represented by test specimens. Many samples of other materials are on a trial basis. The test lot is instrumented with a surface wetness meter, a wet candle, and corrosion rate specimens in order to provide the maximum data for correlation. See figures 1-2 and 1-3.

The ground rules for submission of specimens to be tested in CETA by either industrial concerns or government agencies are quite simple. All specimens should be items that NASA/GSFC is now or may become interested in. The test results will be available to MSFN and the donor through a yearly report.
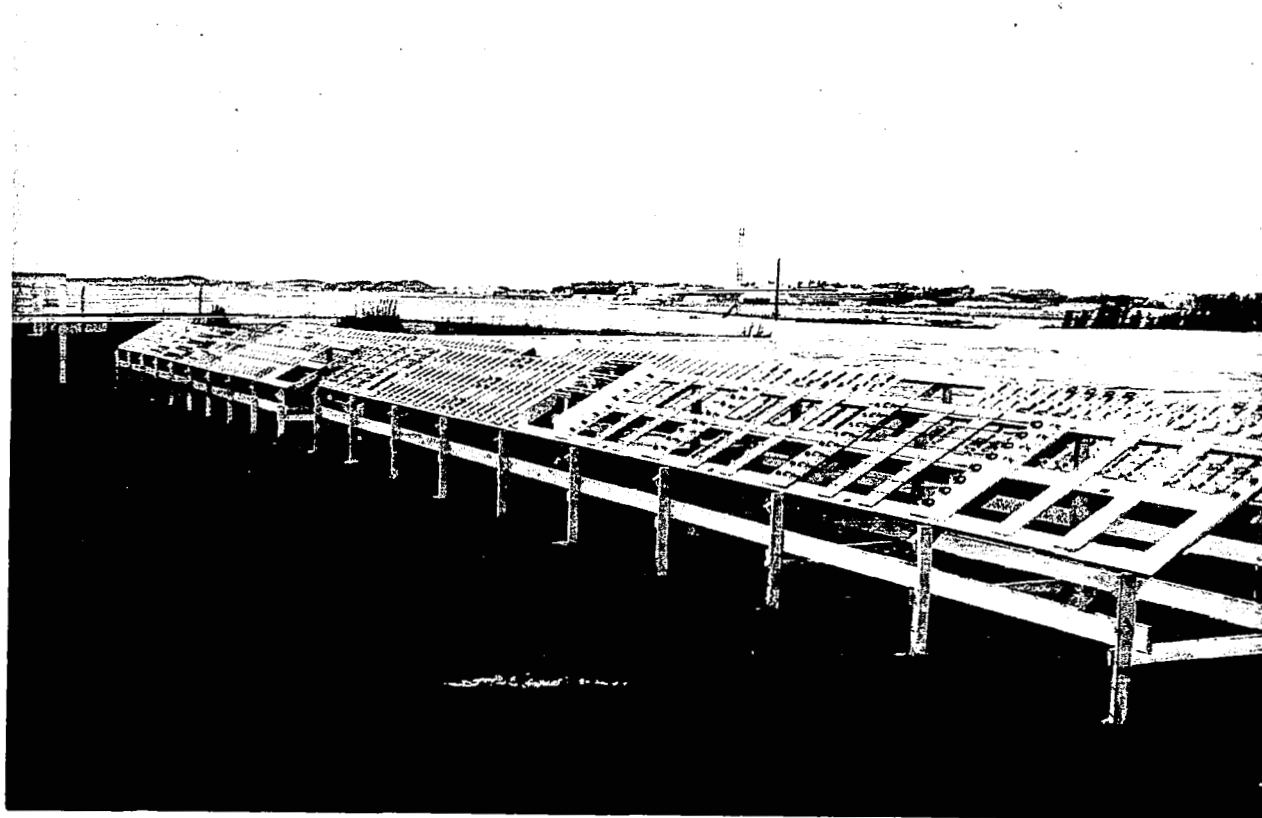
Figure 1-2.   Portion of Project CETA Test Lot
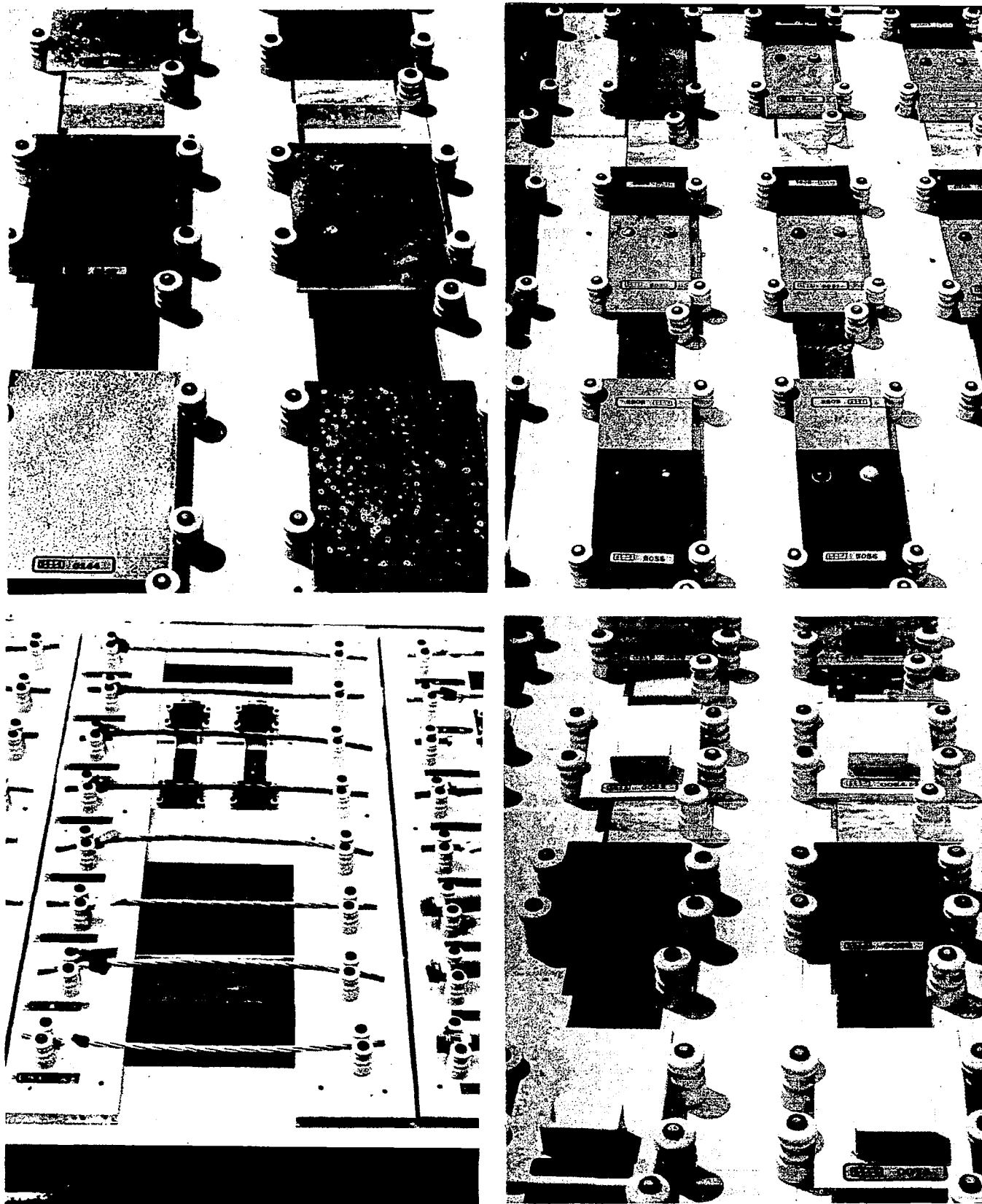
Figure 1-3.   Specimens in Test at Project CETA

CHAPTER II. THE ANATOMY OF CORROSION AT THE MANNED SPACE FLIGHT NETWORK TRACKING STATIONS

INTRODUCTION

2.1 GENERAL

The techniques of controlling the variations of corrosion that are found at the MSFN tracking stations are known; the cost of a corrosion program can be readily justified. Chapter II explores the theory of electrochemical corrosion and illustrates the variations that affect the MSFN tracking station facilities. The variations range from common uniform corrosion to complex intergranular corrosion.

As each variation is identified, areas of concern to the MSFN engineers and technicians are listed. Methods for detection, prevention, and treatment of corrosion are given. Figures illustrate variations of electrochemical corrosion, show actual cases of destruction, and attempt to focus on life-cost alternatives for corrosion control. Research data in tabular form point out danger areas.

The conclusion of Chapter II suggests a minimum training program for station personnel in the knowledge and skills needed to achieve corrosion control at the MSFN tracking stations.

2.2 TECHNICAL

Engineers and technicians who work in the field develop a diagnostic capability and use the scientific method in solving complex problems. Using the scientific method, the basic problem must be identified if a misreading of causes and effects is to be avoided. In solving corrosion problems, it is fundamental that the type of corrosion be identified. For example, treating an intergranular attack as though it were a concentration cell attack is a very expensive and futile exercise if not a serious setback in mission capability. When faced with a corrosion problem, first make a positive identification. Further, the identity should be confirmed before proceeding with control measures. Chapter II will assist in the identification of the variations of electrochemical corrosion at the MSFN tracking stations.

PART A. CORROSION TYPES

2.3 GENERAL COMMENTS ON CORROSION

The forces of nature that affect man's efforts are many and varied. The amounts of money and time spent in offsetting the impact of tides, freezing water, floods, erosion, droughts, earthquakes, and corrosion are formidable. The slowest acting, most undramatic natural force is corrosion. This force is deceiving because it works slowly; however, corrosion comes sharply into focus when it is related to the cost of operation. This cost is not yet known for the MSFN tracking stations, because the experience factor is not well established, but it is known that many of the facilities are located in the most highly corrosive environments of the world. The dollars lost because of corrosion do not tell the entire story; poor quality production, inferior products, safety hazards, and mission degradation or breakdown are indirect effects, and their impacts can be monumental.

Metals are usually found as ores in the oxide form, their lowest energy level state. When man refines a metal, nature begins at once to return it to its lowest energy level. The rate of corrosion on any specific metal varies with temperature, humidity, and chemicals in the surrounding environment. Variations of intensity of these factors have great impact on the rate of corrosion. Ferrous metals that have been exposed to Arctic and Antarctic low temperatures and the absence of electrolytes for 25 years show practically no corrosion, and those that have been exposed to dry desert environments for 50 years without electrolytes show a very low corrosion rate. Rules of thumb indicate that a temperature increase of 10°C doubles the chemical activity if a suitable electrolyte is present. An increase in humidity or conductivity increases the rate of corrosion accordingly. When the environment contains several

factors that aid corrosion, the corrosion rate is usually greater than the resultant of the forces would indicate. Controlled experiments have shown the manner in which corrosion rates are affected by certain factors. For example, figure 2-1 illustrates corrosion rate differences resulting from the two environmental variables of oxygen concentration and temperature.

2.4 ELECTROCHEMICAL CORROSION

Corrosion processes of interest to the MSFN are electrochemical in nature. Three ingredients are required: an electrolyte, a material to act as an anode, and another to act as a cathode. The electrolyte is the medium in which ionization occurs. The electrons flow from the anode to the cathode through a metallic path. The loss of metal is always at the anode. Figure 2-2 illustrates the electrical and chemical interplay of electrochemical corrosion.

Anodic reactions are always oxidation reactions which dissolve the anode metal and force it into solution as ions, or chemically change it to an oxide. Cathodic reactions are always reduction reactions and usually have no effect on the cathode because most metals cannot be further reduced. The electrons liberated by the anodic reaction flow through the metal and are involved in the cathodic reaction. The disposition of the reaction products plays a large role in controlling the rate of corrosion. Sometimes, these reaction products form insoluble compounds which may cover the
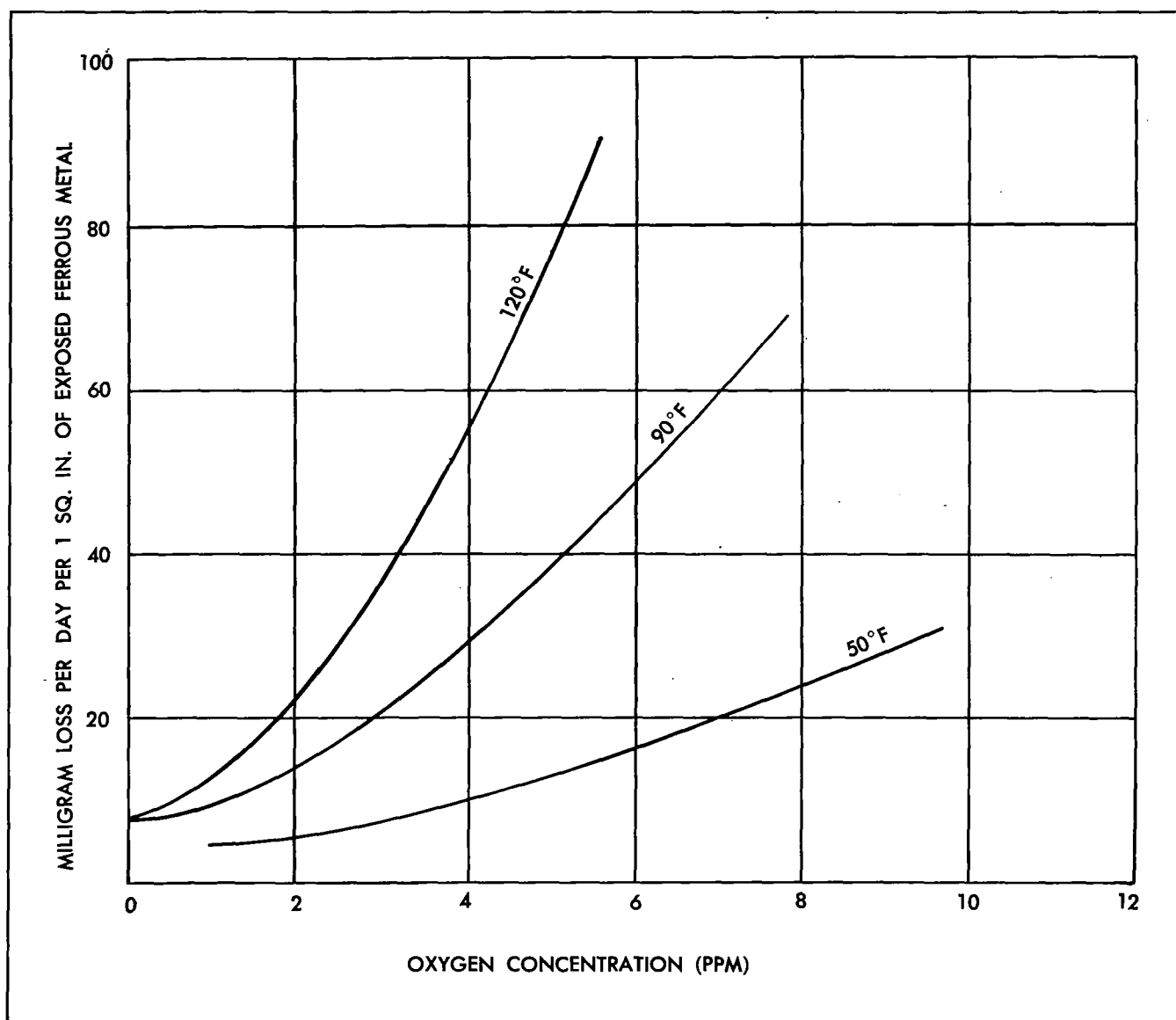
Figure 2-1. Corrosion Rates

ELECTROLYTE

$Fe(OH)_2$

$(OH)^-$

CATHODIC REACTION

$H_2O + 2e^- + 1/2\ O_2 \rightarrow 2(OH)^-$

Fe^{++}

ANODIC REACTION

$Fe \rightarrow Fe^{++} + 2e^-$

ATTACK

COPPER CATHODE   ELECTRON CURRENT   IRON ANODE
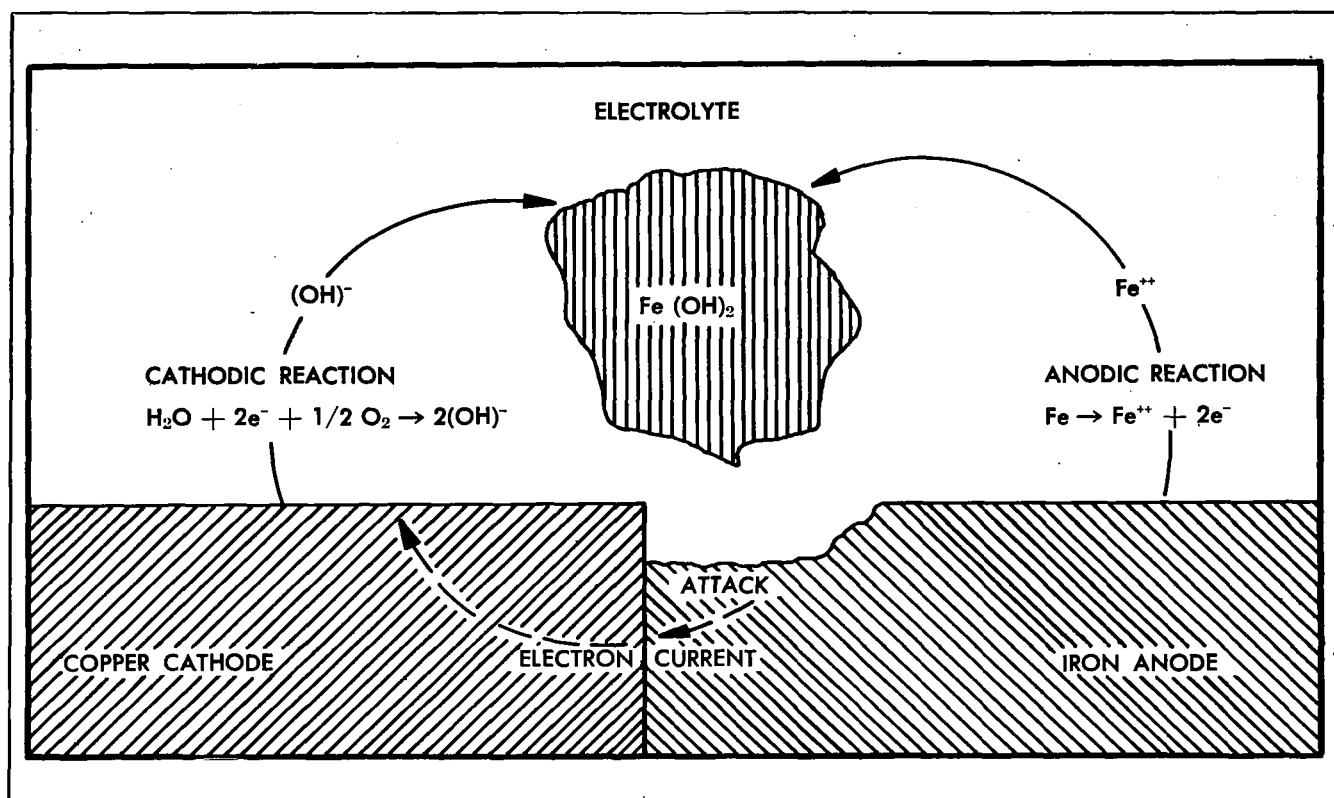
Figure 2-2. Electrochemical Corrosion Circuitry

metal surface and effectively reduce the rate of further corrosion. At other times, they may go into solution or be evolved as a gas and do not inhibit further reaction.

Corrosion occurs at the rate which an electrical current, the corrosion driving current, can get through the corroding system. The driving current level is determined by the existing electrode potentials. Electrode potential is the tendency of a metal to give up electrons. This can be determined for any metal by measuring the potential between the specimen (metal) half cell and the standard (hydrogen) half cell. Tabulating the potential differences between the standard hydrogen half cell and other elements opens an extremely important window to view one part of the corrosion spectrum. Such a tabulation, also known as the electromotive series, is illustrated in table 2-1.

The electrode potential of each metal in table 2-1 was determined using the standard hydrogen half cell. Listing the electrode potentials determined against a single standard forms an electromotive series. Different electrode potentials would result if determined against another standard. Electrode potentials determined under laboratory and field conditions may show considerable differences.

Table 2-1. Electromotive Series

Mg, Mg^{++} *		+2.34 volts †
Al, Al^{+++}		+1.67 volts
Zn, Zn^{++}		+0.76 volt
Cr, Cr^{++}		+0.71 volt
Fe, Fe^{++}		+0.44 volt
Cd, Cd^{++}		+0.40 volt
Co, Co^{++}		+0.28 volt
Ni, Ni^{++}		+0.25 volt
Sn, Sn^{++}		+0.14 volt
Pb, Pb^{++}		+0.13 volt
H_2, H^+	$\leftarrow$ Standard $\rightarrow$	0.00 volt
Bi, Bi^{+++}		−0.23 volt
Cu, Cu^{++}		−0.34 volt
Hg, Hg^{++}		−0.80 volt
Ag, Ag^{++}		−0.80 volt
Pt, Pt^{++}		−1.2 volt
Au, Au^+		−1.7 volt

Notes

† Oxidation reaction voltages
* +indicates valences

Utilizing the electromotive series table, the engineer can determine the electrical potential between any two elements; this electrical potential is the algebraic difference between the single electrode potentials of the two metals. For example:

a. Zinc and Copper

$+0.76 - (-0.34) = +1.10$ volts potential

b. Iron and Copper
   $+0.44 - (-0.34) = +0.78$ volt potential

c. Silver and Copper
   $-0.80 - (-0.34) = -0.46$ volt potential

The electromotive series forms the basis of several possibilities for controlling and decreasing corrosion rates. It provides the data required to calculate the magnitude of the electrical driving force in a galvanic couple. The electrical driving force of an iron and copper couple may be thought of as promoting the following activities:

a. Oxidation of the iron (the anodic reaction) (E_1)

b. The flow of electrons through the solid iron and copper couple (R_2)

c. The cathodic reaction on the copper (reduction) where the electrons are used (E_3)

d. The current (ionic) of Fe^{++} and $(OH)^-$ in the electrolyte (R_4)

The corrosion current forms a closed loop and passes through each of the above steps. It can be calculated as follows:

$$i = \frac{E_1 - E_3}{R_2 + R_4}$$

This corrosion current formula points to various routes that will reduce the rate of corrosion such as:

a. The metallic resistance of the iron and copper couple (R_2) can be increased enormously by insulating the iron from the copper, thus reducing the corrosion current.

b. The electromotive series illustrates that the potential between E_1 (iron) and E_3 (copper) can be reduced by the selection of other metals as denoted in table 2-1.

c. Polarization, the massing of the reaction products in the electrolyte near the anode or cathode, forms a protective layer and reduces the corrosion rate. For example, in a nonacid electrolyte, hydrogen can cover a copper cathode and slow the reaction. With an acid-type electrolyte, however, the hydrogen atoms can combine and escape as hydrogen gas. Polarization is impossible when oxygen dissolving in the surface of the electrolyte combines with the hydrogen around the cathode and destroys the polarizing layer of hydrogen by:

$$1/2\ O_2 + 2H = H_2O$$
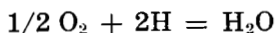
d. The electrolyte can be denied access to the metallic surface by use of a protective coating: a paint system. This prevents ionization of the metal which, of course, arrests corrosion.

2.5 VARIATIONS OF ELECTROCHEMICAL CORROSION

The electrical and chemical facets of electrochemical corrosion assume various postures and levels in different circumstances. This leads to variation in appearance, attack procedure, etc., but the basic circuit shown in figure 2-2 holds true. The MSFN tracking stations are subject to a wide range of electrochemical corrosion variations; in the following pages, the theory and practical side of the variations are illustrated and discussed.

All the varieties of corrosion attack that occur in industry in general do not apply to the MSFN antennas and facilities. For example, the MSFN is not concerned with either low-temperature corrosion of economizers and preheaters in large oil-fired boilers, or high-temperature corrosion, which occurs without the familiar electrolyte. However, there are many forms of electrochemical corrosion that are pertinent to the tracking station antennas and facilities. Those that do have an impact are detailed and illustrated in paragraphs 2.5.1 through 2.5.9.

2.5.1 UNIFORM ATTACK CORROSION

Uniform attack corrosion is characterized by a general disappearance or dissolving of a metal surface due to acidic or oxidizing conditions; it is a general uniform wasting away of the surface. It is not necessary to have two different metals or a galvanic couple to have corrosion. The electric driving force or corrosion current can be present on a single metal. This is shown quite plainly in table 2-1, the electromotive series, where $E_{Fe} - E_H = 0.44 - 0.0 = 0.44$ volt. The microscopic anodic and cathodic areas on the exposed surface of a metal fluctuate and produce a uniform corrosion unless any of the anodic or cathodic areas are stabilized; when this happens severe local corrosion or pitting results. Stabilization may result when dirt on a metal surface, in contact with an electrolyte, diffuses or lessens the oxygen available; the spot stabilizes as an anode and severe corrosion results. Keeping such surfaces very clean to prevent anodic and cathodic stabilization ensures a slower and uniform corrosion. However, differences in electrolyte concentration,* oxygen concentration, temperature, stress, illumination, bacteria count, etc., can stabilize normally fluctuating microanodic and microcathodic areas. Figure 2-3 depicts uniform attack corrosion.

* The requirement for quantity of electrolyte can be misleading. For example, airborne impurities carrying moisture and corrosion accelerators will cause a rapid rate of corrosion on iron even though the dew point is never reached.
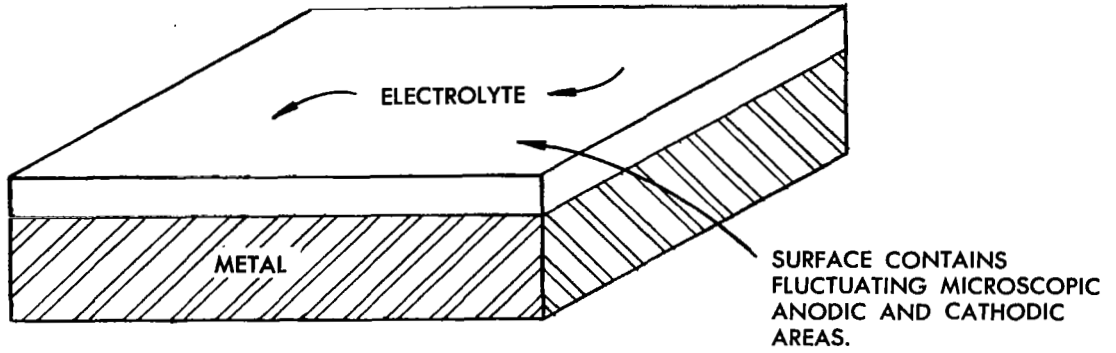
DEPICTION OF UNIFORM CORROSION
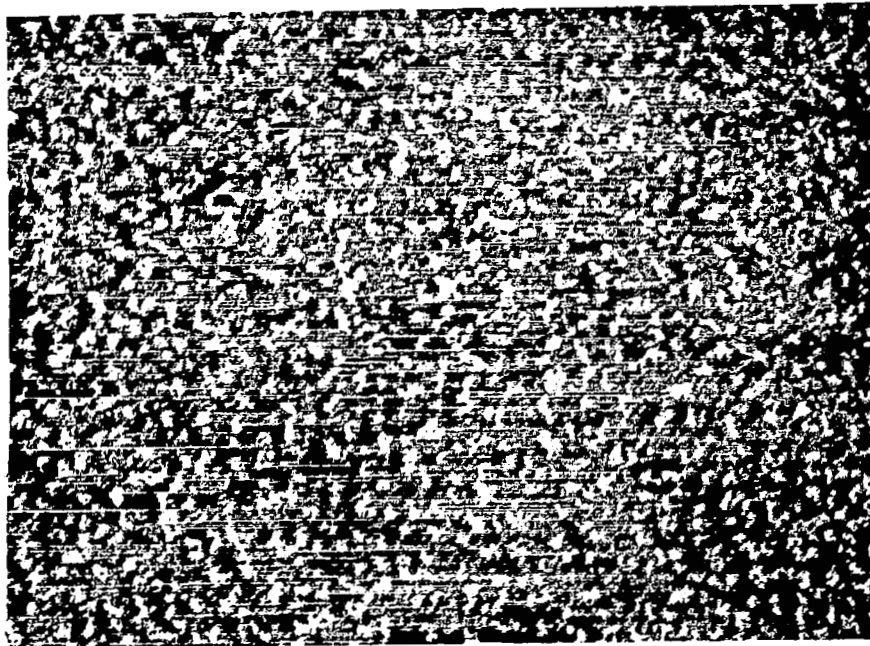
UNIFORM CORROSION ON FLAT STEEL PLATE

Figure 2-3. Uniform Corrosion

Areas of concern to the MSFN tracking stations are as follows:

   a. Exposed sheet metal surfaces

   b. Metal free of any surface contamination

   c. Metal repeatedly cleaned (brake disks)

   d. Reflecting surfaces.

Method of detection is by visual inspection.

Prevention and treatment methods are as follows:

   a. Use corrosion resistant metals where possible

   b. Use polarizing and/or barrier oils to prevent moisture from reaching the metal surface

   c. Schedule cleaning of the surfaces

   d. Use protective coating systems (paints)

   e. Use radomes

   f. Use enclosures on subsystems.

2.5.2 STRESS CORROSION

The variations of stress corrosion applicable to the MSFN facilities are described in paragraphs 2.5.2.1 through 2.5.2.4.

2.5.2.1 INTERGRANULAR CORROSION.
This corrosion action takes place in the grain boundary areas of certain types of metals. Because a discussion of the subject of intergranular corrosion in many metals would be lengthy, the phenomenon will be examined in stainless steel only. Intergranular corrosion is often written about as part of a work on stress-corrosion cracking; although intergranular corrosion can be encouraged by stresses, it is not necessarily caused by stress. When unstabilized chromium nickel steels (austenitic stainless steels) are held in or cooled slowly through the range of 800° F to 1500° F, chromium carbide is precipitated at the grain boundaries. The dilution of chrome in the grain boundaries makes these areas anodic to the surrounding areas. The corrosion usually starts at the surface in the anodic areas and penetrates the metal. It then proceeds probably as an oxygen concentration cell-type corrosion, because the new stainless steel exposed by the advancing corrosion cannot repassivate itself in a low-oxygen concentration area. Certain stainless steels can repassivate themselves by forming a microscopic film of chromium oxide. When a steel under intergranular attack cannot repassivate, the end result can only by deterioration to structural failure. Figure 2-4 illustrates the grain boundary penetration of intergranular corrosion.

Areas of concern to the MSFN tracking stations are as follows:

   a. Welded seams

   b. Stressed relieved austenitic stainless steel where heat treatment was in the 800° F to 1500° F range

   c. Stainless steels with low-chrome content in harsh environment*

   d. Brake discs

   e. Aluminum plates and extruded parts.

Methods of detection are as follows:

   a. Visual inspection
      (1) Leafing
      (2) Swelling

   b. Sonics

   c. Dye Chek

   d. Magnaflux.

Prevention and treatment methods are as follows:

   a. Proper welding techniques

   b. Proper stress relief (Heat higher than 1500° F then cool rapidly through sensitizing range, 1500° F to 800° F.)

   c. Proper stainless steel alloys to prevent carbide precipitation

   d. Proper metallurgy for aluminum parts

   e. Protective coatings in harsh environments

   f. Cutting out, repairing, overpatching, or replacing the defect.

2.5.2.2 TRANSGRANULAR CORROSION.
Transgranular corrosion cuts across or through the grain structure and is not limited to following grain boundaries. The pattern of transgranular corrosion where growth proceeds by branching is called the tree effect. This is stress corrosion and only tensile stresses are effective in promoting the damage. The exact correlation between environments and this type of corrosion has eluded the researchers thus far. There is still much controversy about the manner of propagation. One theory advocates electrochemical action only; another proposes a cyclical electrochemical and mechanical effort. Transgranular corrosion leading to cracking of single-phase alloys such as stainless steels provides an interesting challenge for the electrochemical-only theory. It is difficult to determine why the advancing transgranular corrosion follows such an irregular path; it presents a much more pro-

* Refer to table 2-4.

ATTACK BEGINS ON SURFACE AND FOLLOWS
THE BOUNDARY AREAS IN THIS MANNER.

GRAIN

GRAIN

CHROMIUM AT GRAIN
BOUNDARIES

CORROSION DUE TO
CHROMIUM DEPLETION
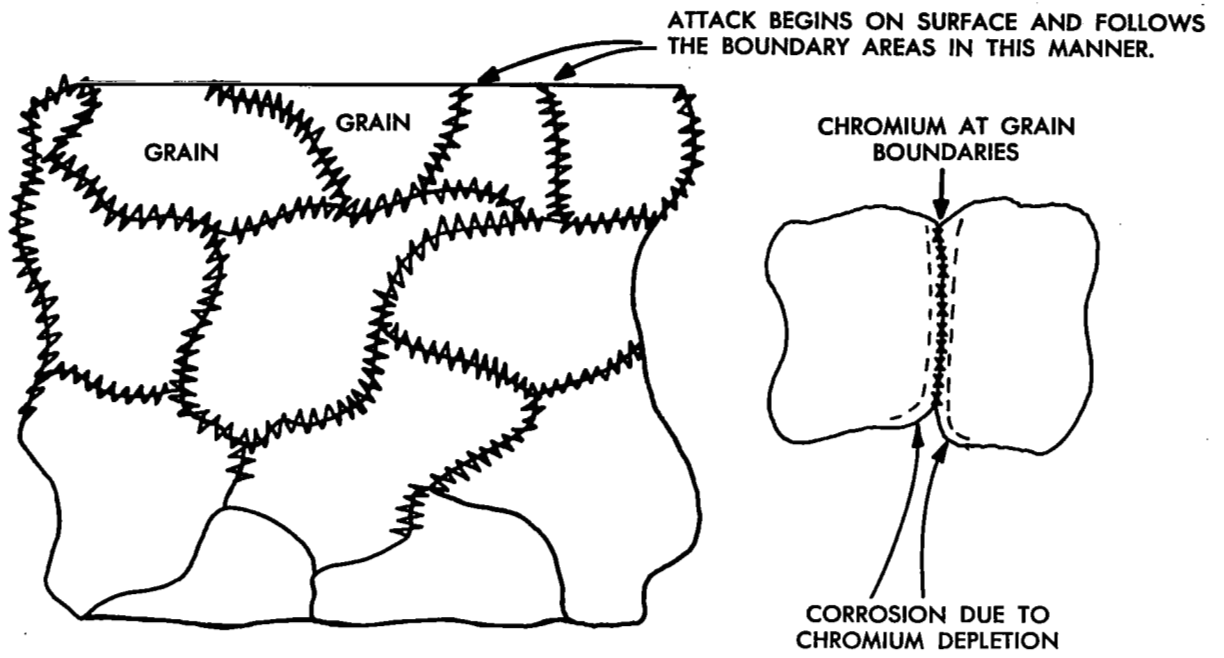
DEPICTION OF INTERGRANULAR CORROSION
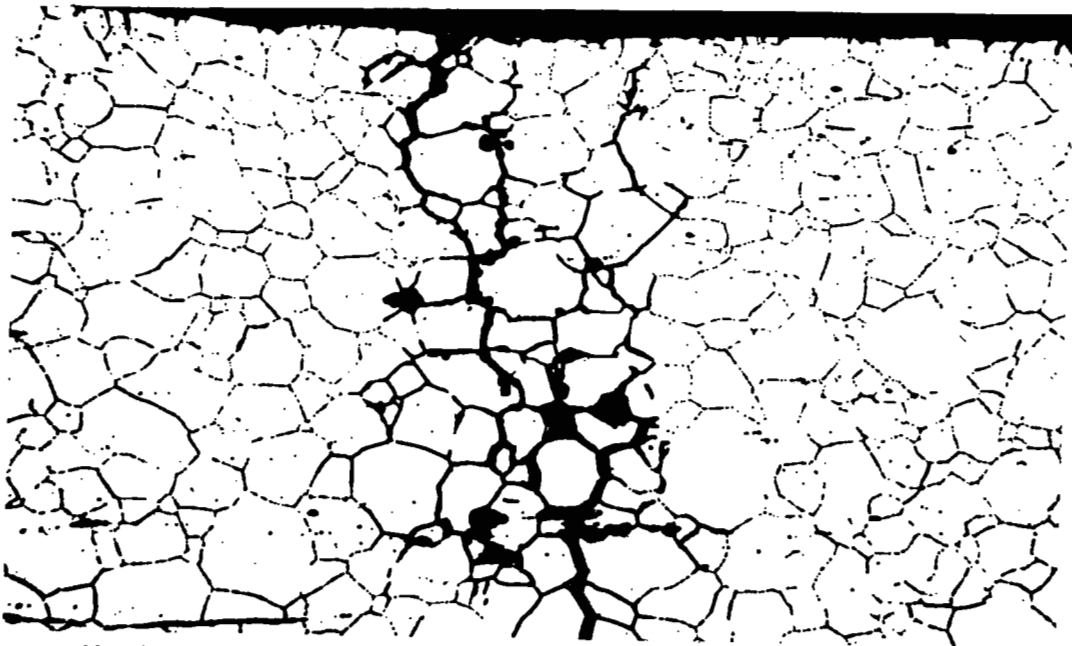
MICROPHOTO OF INTERGRANULAR CORROSION

Figure 2-4.   Intergranular Corrosion

found problem than the intergranular path. The following proposed theories for the path selection of transgranular-corrosion cracking are quite interesting and seem to center more on metallurgical than environmental facets.

    a. Microsegregation of solute atoms to moving crystal imperfections at tip of crack

    b. Static crystal imperfections

    c. Moving crystal imperfections, yielding metal at tip of crack

    d. New corrosion, sensitive phases nucleated by metal deformation at tip of crack.

In addition, there are proponents of a mechanical step who believe that the electrochemical action alone is not sufficient to propagate transgranular-corrosion cracking. The problem is important to designers, operators, and maintainers of structural complexes. Figure 2-5 illustrates the routes of transgranular-corrosion cracking.

Areas of concern to the MSFN tracking stations are as follows:

    a. Design phases

    b. Loadings in excess of design because of very high winds, etc.

    c. Environmental impact (still much to be learned).

Methods of detection are as follows:

    a. Visual inspection

    b. Sonics

    c. Dye Chek

    d. Magnaflux.

Prevention and treatment are as follows:

    a. Proper design (There is a load limit below which the metal will not crack from transgranular corrosion regardless of the cyclical movements.)

    b. Proper protective coatings

    c. Removal and repair.

2.5.2.3 CRACKING. Stress corrosion, which may lead to stress-corrosion cracking of the metal, is a separate category of metal failure; it is not a straight mechanical failure because its origin is not entirely mechanical. Neither stress nor corrosion when operating independently will cause stress-corrosion cracking. However, structural failures resulting from stress-corrosion cracking may occur in an environment where the corrosion rates are quite low and the actual stress loading is far below design limits. The causes of these

stresses are quite varied; there are operational stresses due to design, residual stresses resulting from fabrication and heat treatment, and stresses generated by corrosion. Two different concepts regarding the mechanism of stress-corrosion cracking prevail at the time of this writing. One theory states that stress-corrosion cracking is solely an electrochemical process, progressing at right angles to the prevailing tensile stress. This is the classic electrochemical action where the stress areas are anodic to the unstressed areas. Another theory states that electrochemical corrosion proceeds to a point and triggers a minute mechanical fracture, and the electrochemical action starts anew. This electrochemical and mechanical action is cyclical and can proceed to structural failure. Stress-corrosion cracking can proceed in a transgranular mode or follow grain boundaries in an intergranular mode. Figure 2-6 illustrates the phenomenon of stress-corrosion cracking.

Areas of concern to the MSFN tracking station facilities are as follows:

    a. Structural members under static tensile stress

    b. Structural members under flexing tensile stress

    c. Turnbuckles

    d. Bolts under high tension

    e. Exposed gear teeth.

Methods of detection are as follows:

    a. Visual inspection

    b. Misalignment checks

    c. Dye Chek

    d. Sonics.

Prevention and treatment are as follows:

    a. Proper structural design

    b. Proper metallurgical treatment of metals

    c. Additional support for tensile stressed structural members in existing structure

    d. Protective coatings

    e. Dampening cyclical activity.

2.5.2.4 EXFOLIATION. Exfoliation is a type of stress corrosion characterized by a rapid advance along the grain boundaries or striations within the grains parallel to the surface. This directional advance or attack appears as leafing. The attack is aggravated by the relatively large volume of corrosion residue buildup and results
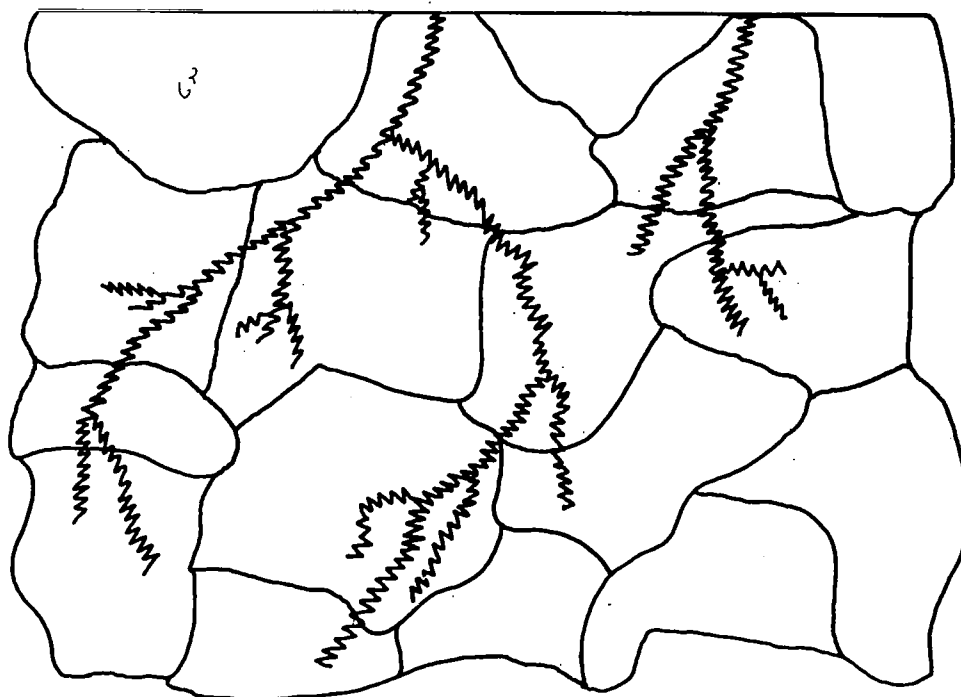
DEPICTION OF TRANSGRANULAR CORROSION.

MICROPHOTO OF TRANSGRANULAR CORROSION.

Figure 2-5.   Transgranular Corrosion
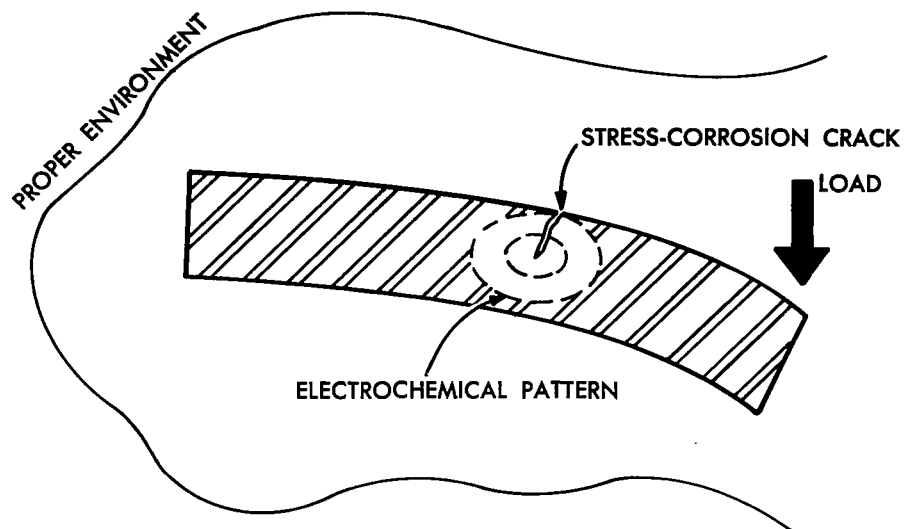
DEPICTION OF STRESS-CORROSION CRACKING
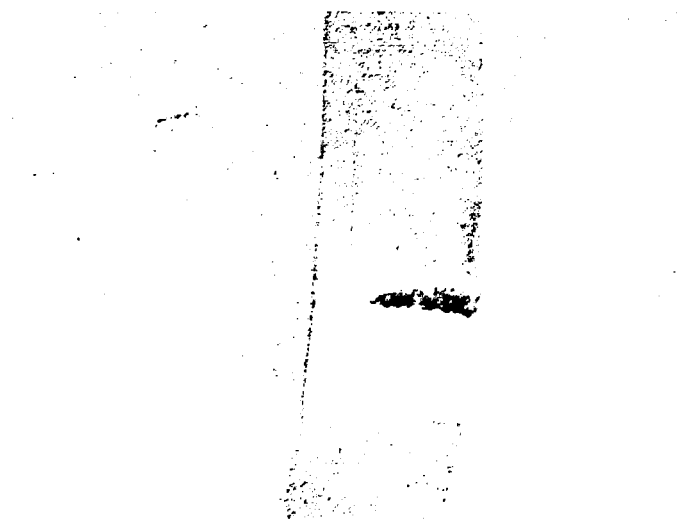
STRESS-CORROSION CRACKING ON STEEL STRIP

Figure 2-6.   Stress-corrosion Cracking

in the splitting of uncorroded strata. Since exfoliation follows the direction of the grain structure, it may be experienced in metals with an elongated grain where the grains are thin compared to width. For example, Al-Mg, Al-Cu, and Al-Zn-Mg-Cu alloys in the form of light gage (0.20 to 1.0 inch) extruded shapes and plates may experience exfoliation attack when exposed in harsh environments. The susceptibility of exfoliation can be lessened by proper metallurgical steps. T 851 temper for the 2024 aluminum alloy and T 73 temper for the 7075 aluminum alloy are examples of increasing corrosion resistance by metallurgy. The increase in resistance to exfoliation is usually made by sacrificing tensile strength. However, since the effect of corrosion itself is a loss of strength, the answer is a compromise between immediate and lifetime strengths and corrosion. It is a matter that should be resolved in the very early stages of design.

Exfoliation is greatly accelerated in harsh (seacoast) environments where the metal is subject to saline contamination. Few metals, if any, are immune to exfoliation attack given the proper stress and environment. Figure 2-7 illustrates exfoliation corrosion attack.

Areas of concern to the MSFN tracking station facilities in harsh environments are as follows:

  a. All plates and extruded metals

  b. Counterweight bolts on the USB antennas

  c. Gusset plates riveted on the back side of the dish panels

  d. Countersunk holes for fasteners

  e. Unprotected metal edges (exposed grain ends).

Methods of detection are as follows:

  a. Visual inspection
     (1) Swelling
     (2) Leafing

  b. Sonics.

Prevention and treatment are as follows:

  a. Design compromise where some sacrifice of tensile strength is made to achieve higher exfoliating resistance

  b. Protection from saline wetness by anodizing, plating, and paint systems

  c. Replacement of exfoliating member.

2.5.3 PREFERENTIAL OR SELECTIVE CORROSION

This corrosion is exemplified by the loss of one of the metals of an alloy. The corrosion process begins when one element in an alloy becomes anodic to the other and is preferentially attacked. This slow disappearance of zinc from a zinc copper alloy (brass) is a phenomenon not frequently seen, but it can be disastrous because the porous copper mass depleted of zinc, its alloying agent, has little strength. Plug-type (localized) dezincification can be very severe and destroy the usefulness of the item with very little loss of metal. Under certain conditions, the Fe in cast iron is

Figure 2-7. Exfoliation Corrosion Attack

depleted by selective corrosion, leaving a strength-less graphite shell. A similar effect happens to copper piping and tubing when they are used to carry demineralized water; the copper metal goes into solution in the form of copper ions in the water. Figure 2-8 illustrates typical preferential corrosion problems.

Areas of concern to the MSFN tracking stations are as follows:

    a. Heat exchanger tubes

    b. Utility lines

    c. Various lines and gaskets on diesel engines

    d. Waveguide filters.

Methods of detection are as follows:

    a. Visual inspection

    b. Chemical testing.

Prevention and treatment are as follows:

    a. The use of brasses with less than 15 percent zinc

    b. The use of alloying elements such as tin or arsenic in high-zinc alloys

    c. The control of temperature

    d. The control of pH

    e. Degasification

    f. The use of glass, stainless steel, plastics, and corrosion-resistant materials for utility lines.

2.5.4 LOCAL CORROSION

Local corrosion is a pitting type of electrochemical deterioration. One major cause of local corrosion is a rupture in the protective coating. The exposed metal is stabilized as an anode, and the surrounding metal or the corrosion products act as the cathode. If the corrosion products build up, they can act as a barrier to the free flow of oxygen, and the action may continue as a differential concentration cell-type corrosion. Local corrosion activity can severely pit underground utility lines wherever the protective coating is broken. This type of attack can be quite deceiving because a relatively small number of pits can destroy a utility system, or a small concentration of local corrosion pits can destroy the mechanical integrity of a structural member or an entire structure. Figure 2-9 shows the electrochemical circuitry and a section of structural steel with local corrosion pits. (The steel has been cleaned to show the pits.)

Areas of concern to the MSFN tracking station facilities are as follows:

    a. Any breaks on protective coatings

    b. Unprotected, buried, metallic utility lines and structures

    c. Complicated structural areas at points where proper surface preparation and repair painting are difficult

    d. Points of high moisture retention.

Methods of detection are as follows:

    a. Detailed inspection on a scheduled basis

    b. Resistivity plots or inspection holes on buried lines and structures.

Prevention and treatment are as follows:

    a. Bitumin coating and wrapping and 10,000-volt wire-brush test

    b. Nonmetals for underground utility lines

    c. Scheduled inspections and proper repair of protective coatings

    d. Cathodic protection

    e. Good moisture dissipation.

2.5.5 CAVITATION

Once thought to be caused by poor metal alloys and to result from the implosive forces of very small collapsing bubbles, cavitation is now believed to result from high-frequency vibration, implosive stress, and chemical action. A combination of the action agents creates a faster deterioration than the resultant of their single actions would indicate. See figure 2-10.

Areas of concern to the MSFN tracking station facilities are as follows:

    a. Centrifugal pump impellers

    b. Wet sleeve liners for diesels.

Methods of detection are as follows:

    a. Periodic inspection

    b. A drop in pump capacity or head

    c. Coolant in diesel crankcase oil.

Prevention and treatment are as follows:

    a. The maintenance of coolant liquid below flash point ($15°F$ below flash point or 10 psi above flash point)

    b. Alteration of cooling medium density

    c. Alteration of vibration pattern

SPOT DEZINCIFICATION
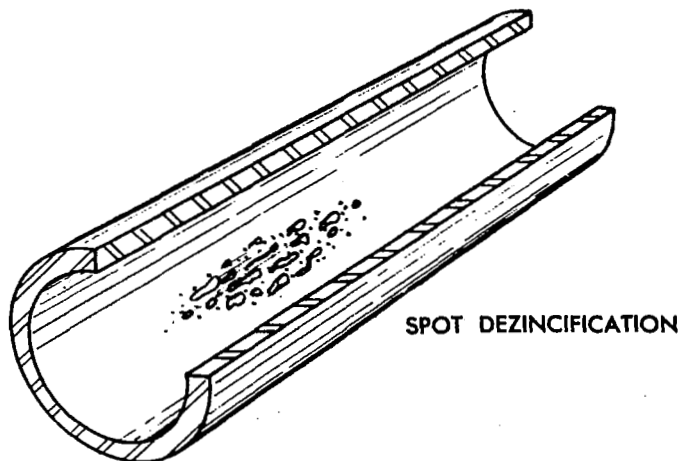
ATTACK APPEARS CONCENTRATED AT NUMEROUS SPOTS WITH AREAS
BETWEEN UNDER NO ATTACK (SOMEWHAT SIMILAR TO ENTRAINED
OXYGEN ATTACK ON FERROUS METAL). CORROSION FOUND IN
AREAS OF HIGH FLOW.

LAYER DEZINCIFICATION

PHENOMENON USUALLY RESULTING IN NO-FLOW AREAS

DEPICTION OF PREFERENTIAL CORROSION (DEZINCIFICATION)

PREFERENTIAL CORROSION OF INTERIOR OF UTILITY LINE

Figure 2-8. Preferential Corrosion

CORROSION LAYER

METAL

PIT ANODE
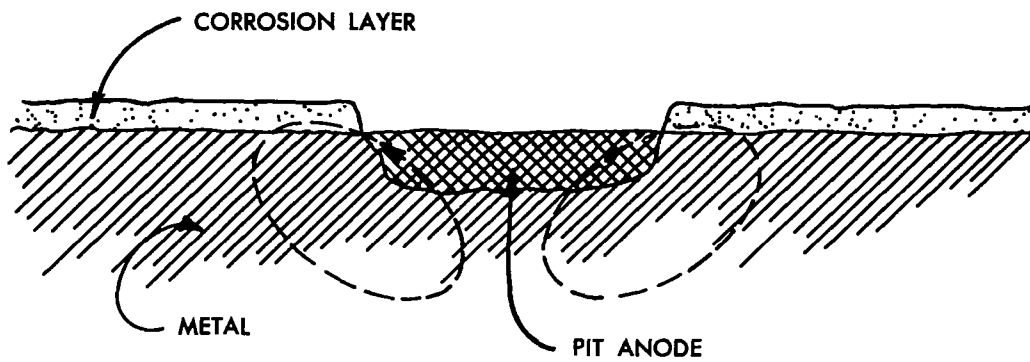
DEPICTION OF LOCAL CORROSION
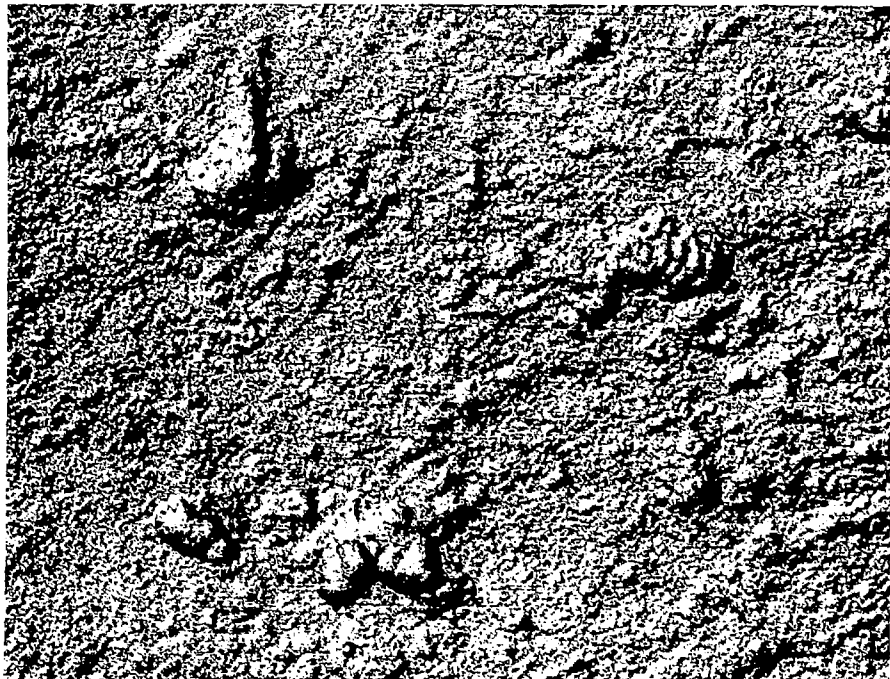
LOCAL CORROSION ON FLAT STEEL PLATE

Figure 2-9. Local Corrosion

WET SLEEVE LINER OF
DIESEL ENGINE

LOSS OF METAL DUE TO
CAVITATION—USUALLY IN A
VERTICAL PATTERN ON THE
WET SLEEVE LINER IN LINE
WITH THE CRANK THROW

"O" RING GROOVES
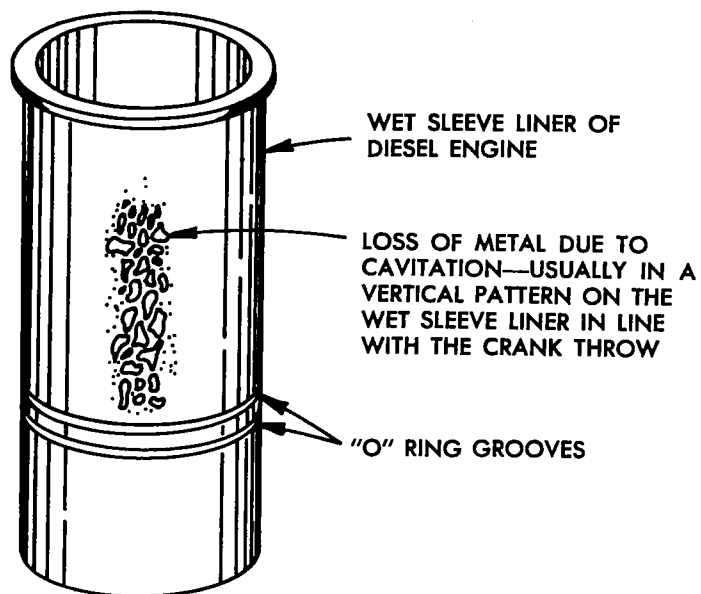
DEPICTION OF CAVITATION
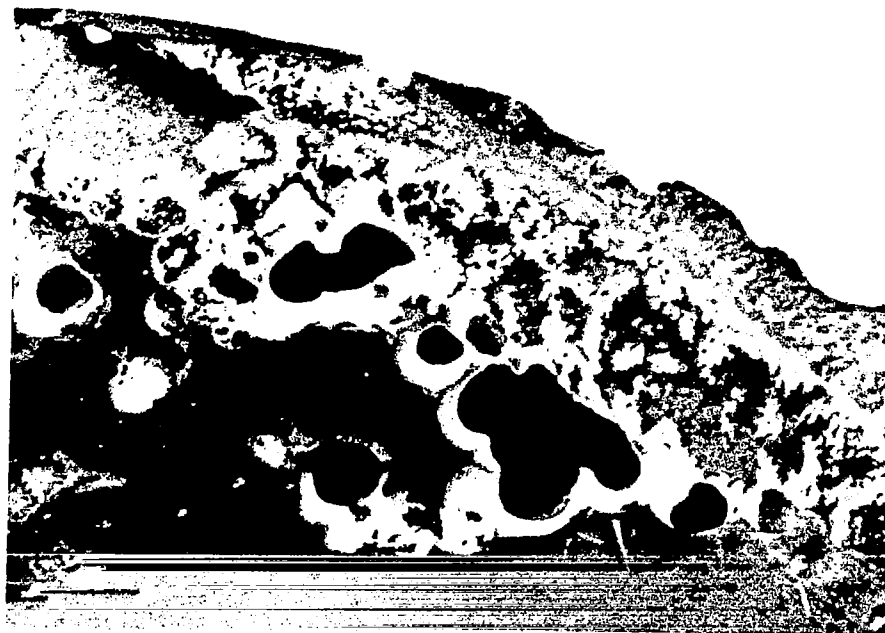
CAVITATION ON PERIPHERY OF PUMP IMPELLER

Figure 2-10.   Cavitation

d. Chemical treatment or deaeration to eliminate entrained oxygen and other dissolved gases

e. The maintenance of a pH between 7.5 and 8.5

f. The purging of air from the system.

Wet sleeve liners that have been subjected to cavitation type destruction may be reinstalled under certain conditions. If an inspection shows cavitation on a liner, it will be noted that the eroded area is usually in line with the crank throw, and, on the side, the cooling water impinges on the liner. When a careful check shows no pit is deeper than 20 percent of the total wall thickness, the liner can be reused. The eroded area should be turned 90 degrees from its original position in order to put it at a right angle to the crank throw. If any pit is deeper than 20 percent of original wall thickness, the liner should not be reused. Repair of such liners has not been too successful.

2.5.6 FRETTING CORROSION

Fretting corrosion seems to be a follow-on action of mechanical fretting caused by an oscillating or vibrating motion of small amplitude between two closely-fitting surfaces; it has also been called friction oxidation. Researchers believe that the unoxidized ferrous particles torn loose by abrading because of the oscillations corrode to Fe_2O_3. The abrasive Fe_2O_3 then assists in more rapid removal of ferrous particles, and, in a short time, the red mud Fe_2O_3 appears. Other iron oxides such as FeO (black) or Fe_3O_4 (black) may also be noticeable. Fretting corrosion appears much more pronounced at oscillations of lower frequencies; 50 cycles per minute generate much more corrosion than 1500 cycles per minute. These small amplitude, low-frequency oscillations are worthy of investigation at structural joints, bolted flanges, keys, bearings, etc. These areas or items which are subject to fretting corrosion either were designed not to move and did, or are bearings that oscillate. Fretting corrosion is not limited to structural and high-grade steels; stainless steels and aluminum are also prone to fretting corrosion if the same conditions previously mentioned are present. The Cr_2O_3 and Al_2O_3 residues found under fretting corrosion circumstances seem to be adequate proof of this. (See figure 2-11.)

Areas of concern to the MSFN tracking station facilities are as follows:

a. Sleeve bearings

b. Precision bearings

c. Keys and keyways

d. Bolted flanges

e. Structural joints (bolted or riveted).

Methods of detection are as follows:

a. Visual inspection (appearances of red or black mud at areas noted above)

b. Oscillation checks

c. Misalignment checks.

Prevention and treatment are as follows:

a. Design for proper loading

b. Proper finishes and fits

c. Higher coefficients of friction for mating metal parts not acting as bearing surfaces

d. Tight joints

e. Control of humidity

f. Dampening shaft vibration

g. Lower viscosity oils

h. Proper lubrication

i. Clean, moisture-free oil and lubricants

j. Submergence of bearings in oil or light, shear-susceptible grease

k. The increase in amplitude of vibration to pull in more lubricant for antifriction bearings

l. Proper tie down during transportation.

2.5.7 GALVANIC CORROSION

Galvanic corrosion is the disintegration of the anode in a galvanic couple. A closed electrical path through two connected dissimilar metals joined by an electrolyte occurs in endless variations and provides some very rapid corrosion rates. A difference of potential between two touching metals when covered by an electrolyte forms a miniature cell with an anode (metal loss, corrosion) and cathode (protected area). Many such corrosion areas are, in effect, small cells or batteries; hence the term galvanic. If the area of the cathode is significantly greater than that of the anode, the corrosive attack on the contact area of the anode may be greatly intensified. When a continual supply of rust is provided by some external source (for example, bolts), unsealed or partially sealed aluminum or zinc coatings will be severely attacked. Zinc and aluminum are strongly anodic to iron.

It is of maximum importance that designers, operators, and maintainers of metallic structures, machinery, and utility systems be familiar with the galvanic series and metallic families within the series. Responsible designers will not permit the joining or intimate contact of certain metals because they create strong galvanic couples and destroy the anode of the couple. Several common but very unwise choices of metal combinations have been steel pipe and bronze valves, brass heads and aluminum gaskets, copper and aluminum, and steel and aluminum. The higher the metal in the

CORROSION SHOWS UP AS
PITS BETWEEN SHAFT AND
INNER BEARING RACE.
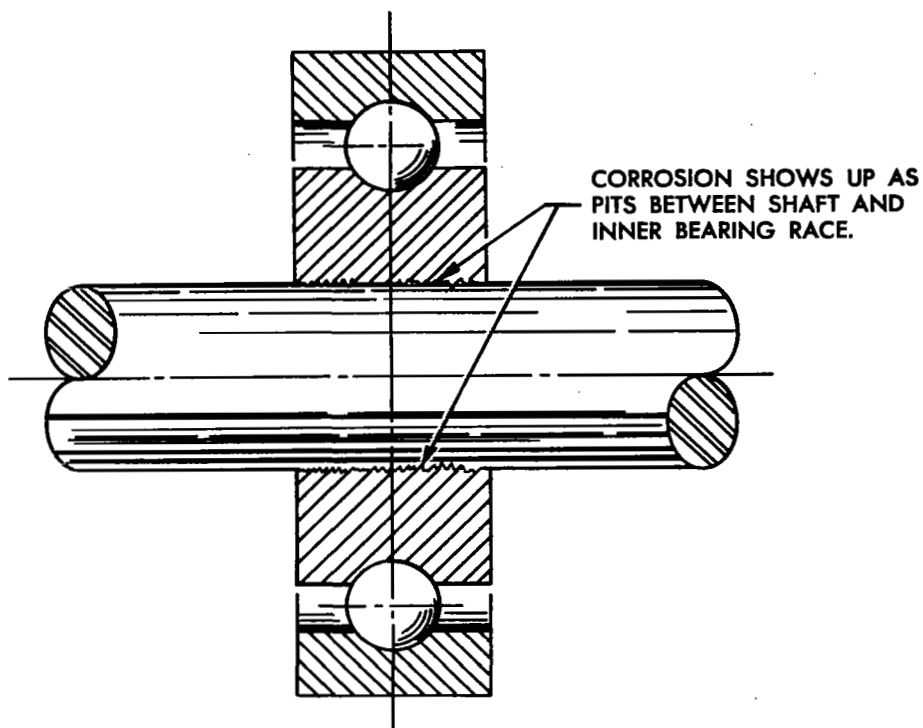
DEPICTION OF FRETTING CORROSION
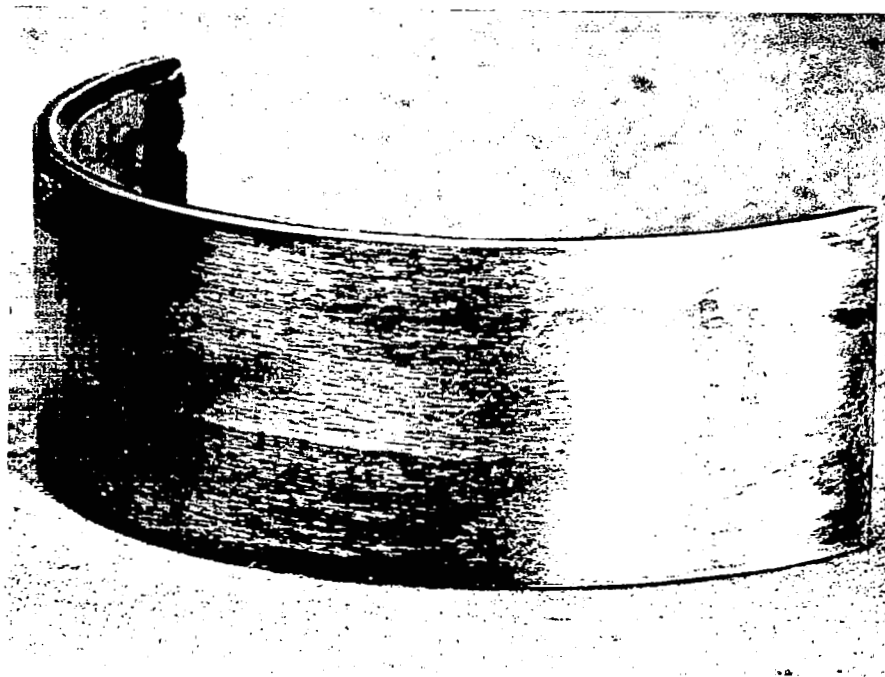
FRETTING CORROSION ON SLEEVE BEARINNG

Figure 2-11.   Fretting Corrosion

galvanic series, the greater its chances of being anodic in a couple of two dissimilar metals. The positioning of many of the most widely used metals in the galvanic series is in table 2-2. Because dissimilar metal couples are necessary for various reasons, the metals used should have, where possible, the least electromotive force between them. A selection of compatible couples are listed in table 2-3. For a couple to be compatible according to table 2-3, the emf between the two metals of the couple must not exceed 0.25 volt. Figure 2-12 illustrates the circuitry and a dramatic example of galvanic corrosion.

Areas of concern to the MSFN tracking station facilities are as follows:

    a. Diesel engines
    b. Pumps
    c. Air conditioners
    d. Valves and piping
    e. Joints of different structural metals
    f. Flexible waveguides.

Methods of detection are as follows:

    a. Visual inspection
    b. Volt potential check

    c. Leaks
    d. Loss of pressure
    e. Metallic swellings (hard metal blisters)
    f. Powder residuum.

Prevention and treatment are as follows:

    a. Proper design, attention to the emf between dissimilar metals
    b. Use of metals adjacent or quite near each other in the galvanic series table (Maximum emf permissible between dissimilar metals in an MSFN structure is 0.25 volt.)
    c. Attempt to make the smaller part of a galvanic couple the cathode member. For example, welding-rod material should be more noble than the material welded, when possible. This adheres to the rule that the cathodic member be smaller than the anodic member.
    d. Insulation of dissimilar metals, for example, dielectric barriers such as mastics, vinyls, teflon, etc.
    e. Elimination of electrolyte, through the use of radomes, by painting, etc.

Table 2-2.   Galvanic Series (Salt-water Electrolyte)

Anodic end of series	
Magnesium [2] Magnesium Alloys [1]	Nickel
Zinc	Inconel [4]
Aluminum	Stainless Steels (Passive)
Cadmium	Titanium
Aluminum Alloys	Silver
Mild Steels Alloy Steels Wrought Iron Cast Iron	Graphite
Stainless Steel (Active)	Gold
Ni-Resist	Platinum [3]
Solders (Soft) Lead Tin	Cathodic end of series
Brasses Copper Bronzes Copper-Nickel	

Notes

[1] Metals within any grouping show little corrosion tendencies when coupled.
[2] Least noble metal
[3] Most noble metal
[4] Inconel is a registered trademark of the International Nickel Company, Inc.
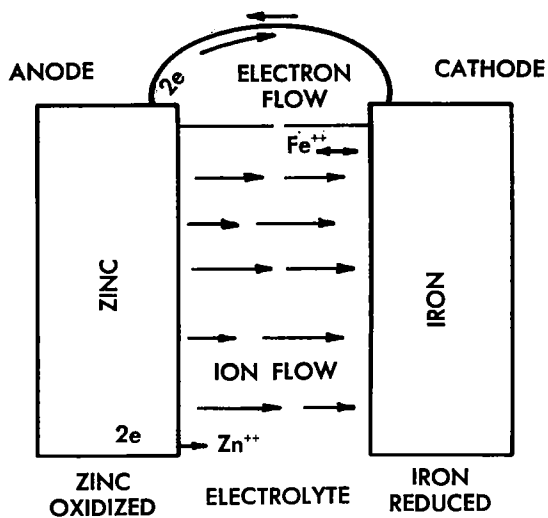
DEPICTION OF A GALVANIC COUPLE CORROSION
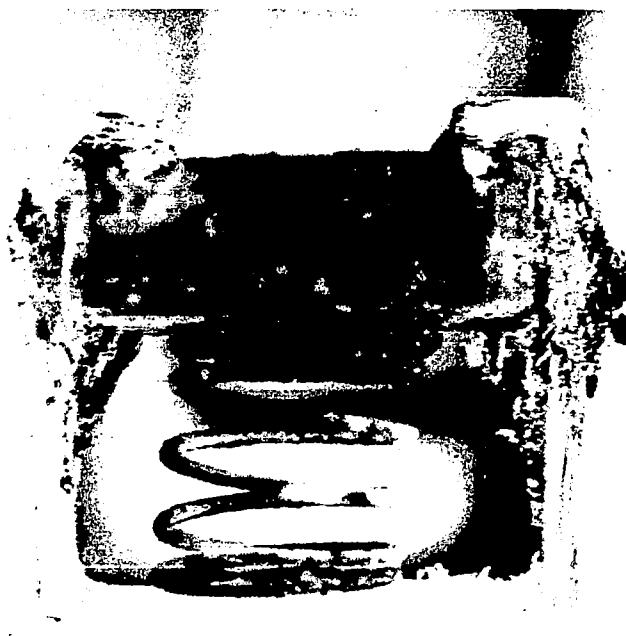
GALVANIC CORROSION OF STEEL NUT IN ALUMINUM CHANNEL

Figure 2-12. Galvanic Corrosion

Table 2-3. Compatible Couples*
(from the Military Specification: MIL-F-14072 [Sig C])

Group No.	Metallurgical Category	E.M.F. (Volt)	Anodic Index (0.1 Volt)	Compatible Couples
1	Gold, solid and plated; Gold-platinum alloys; Wrought platinum	+0.15	0	
2	Rhodium plated on silver-plated copper	+0.15	10	
3	Silver, solid or plated; High silver alloys	0	15	
4	Nickel, solid or plated; Monel metal, High nickel-copper alloys	−0.15	30	
5	Copper, solid or plated; low brasses or bronzes; Silver solder; German silver; High copper-nickel alloys: Nickel-Chromium alloys; Austenitic stainless steels	−0.20	35	
6	Commercial yellow brasses and bronzes	−0.25	40	
7	High brasses and bronzes; Naval brass; Muntz metal	−0.30	45	
8	18% chromium type corrosion-resistant steels	−0.35	50	
9	Chromium, plated; Tin, plated; 12% chromium type corrosion-resistant steels	−0.45	60	
10	Tin-plate; Terne-plate; Tin-lead solders	−0.50	65	
11	Lead, solid or plated; High lead alloys	−0.55	70	
12	Aluminum, wrought alloys of the Duralumin type	−0.60	75	
13	Iron, wrought, gray or malleable; Plain carbon and low alloy steels armco iron	−0.70	85	
14	Aluminum, wrought alloys other than Duralumin type; Aluminum, cast alloys of the silicon type	−0.75	90	
15	Aluminum, cast alloys other than silicon type; Cadmium, plated and chromated	−0.80	95	
16	Hot-dip-zinc plate, Galvanized steel	−1.05	120	
17	Zinc, wrought; Zinc-base die-casting alloys; Zinc, plated	−1.10	125	
18	Magnesium and magnesium base alloys, cast or wrought	−1.60	175	

Notes
○Indicates the most cathodic member of the series, and the arrows, the anodic direction.
●An anodic member

*When in doubt about the potential between any two metals, send a small piece of each metal (one square inch) to Bendix Field Engineering—Facilities Section, Network Support Group, for a series of volt potential tests.

2.5.8 CONCENTRATION CELL CORROSION

Concentration cell corrosion occurs when differential oxygen concentration cells or differential metal ion concentration cells attempt to balance concentration differences. Barriers to the ready transfusion of oxygen create the differential of oxygen concentration. The low-oxygen area is anodic to the high-oxygen area. If an electrolyte on a metal contains more metal ions at one point than at another, metal enters the electrolyte in the form of ions where the ion concentration is low. Low oxygen areas can generate in crevices. The term "crevice corrosion" probably arose because it is descriptive. Corrosion often occurs in cracks between various types of lapped joints and flanges. Actually the so-called crevice corrosion is often concentration cell corrosion due to an oxygen differential in the crack and at the surface. (See figure 2-13.)
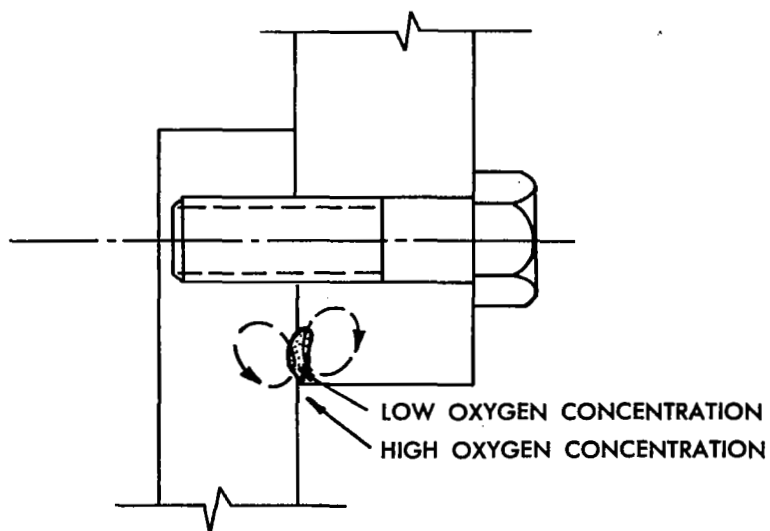
DEPICTION OF CONCENTRATION CELL CORROSION

LOW OXYGEN CONCENTRATION
HIGH OXYGEN CONCENTRATION

CONCENTRATION CELL CORROSION ON FELT-WRAPPED STEEL ARMORED CABLE

Figure 2-13.   Concentration Cell Corrosion

Areas of concern to the MSFN tracking station facilities are as follows:

a. Partially welded seams

b. Bolted and riveted joints

c. Crevices

d. Flanged connections

e. Overlap welds

f. RF connectors.

Methods of detection are as follow:

a. Check crevices, lap joints, intermittent welds, flanges, etc.

b. Blisters on paint coats and metal plating

c. Rust stains.

Prevention and treatment are as follows:

a. Proper design

b. Proper sealing of crevices

c. Flanged connections insulated with dielectric gaskets that leave no voids between the flange faces

d. Butt welds

e. Continuous welds

f. Vapor-proof connections.

2.5.9 MILL SCALE

Mill scale may not be a classic form of electrochemical corrosion because the scale consists of corrosion products. It is formed when hot billets are rolled and undergo temperature changes. The mill scale can adhere very tightly, or it can be relatively loose. When adhering tightly, it is practically unnoticeable. It takes on the appearance of the metal. Since mill scale is at times difficult to identify, difficult to remove, and very destructive to ferrous metals and protective paint systems, it is treated here as an identifiable type of corrosion. See figure 2-14 for the mill scale illustration.

Areas of concern to the MSFN tracking station facilities are all structural iron or steel rolled from billets.

Methods of detection are as follows:

a. Visual inspection

b. Chipping hammer

c. Pickling acid spot tests.

Prevention and treatment are as follows:

a. Mill scale can best be removed by proper pickling.

b. Sandblasting to remove mill scale is a poor second method.

c. Tightly adhering mill scale on most structural members in dry environments is considered acceptable for most uses. This is not advised for very complicated structures such as the MSFN antennas.

CATHODE

ANODE

Fe_2O_3

Fe_3O_4

$Fe\ O$

FERROUS METAL

*MILL SCALE
0.002" TO
0.020" THICK

POTENTIAL DIFERENCE CAN BE AS HIGH AS .35 VOLT.

Fe_2O_3—RELATIVELY STABLE
Fe_3O_4—MAGNETIC OXIDE
$Fe\ O$ —UNSTABLE, CONVERTS TO FERRIC IRON (Fe_2) W/CHANGE IN VOLUME
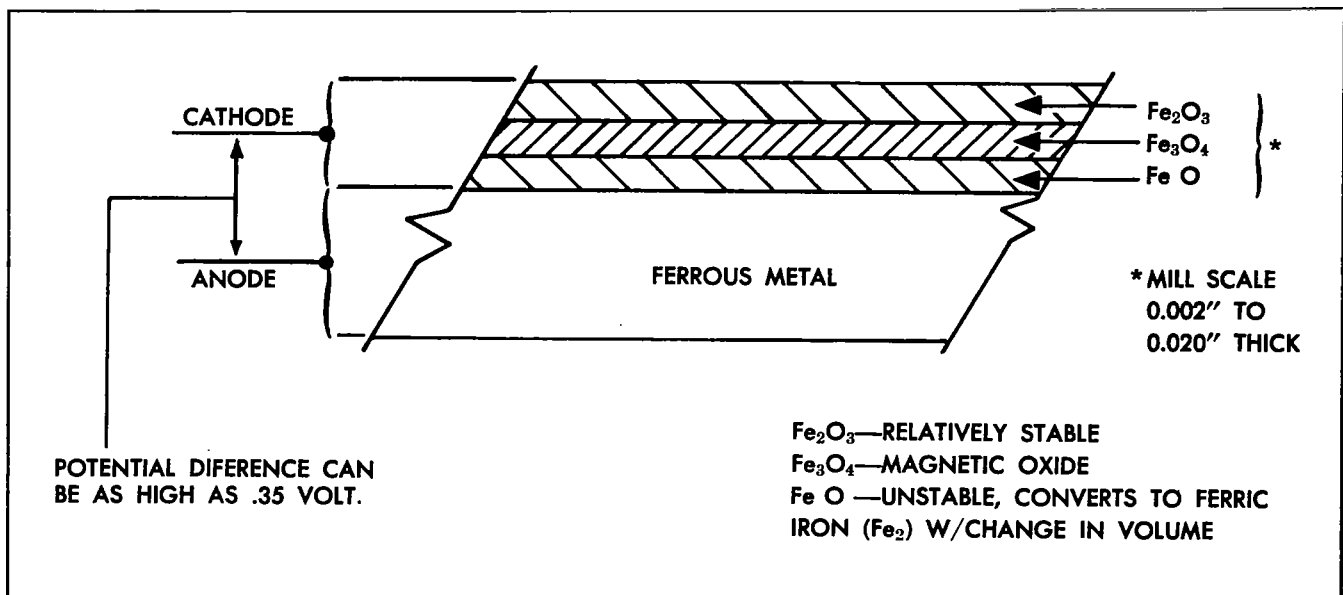
Figure 2-14.   Mill Scale Cross Section

2.6 CORROSION OF FERROUS METALS IN THE ATMOSPHERE

Once started, rusting does not proceed at a uniform rate. The familiar reddish-brown rust on steel is a mixture of hydrated iron oxides. Depending upon the amount of pollution in the atmosphere and the composition of the steel, this oxide film is more or less protective. *Of all common pollutants, sodium chloride found in seacoast (harsh) environments is the greatest destroyer of the protectiveness of the rust film on carbon steel.* Oxides of sulfur are a poor second to sodium chloride. When both pollutants are nearly absent, the corrosion of steel is not significant; a rust film forms and assumes a protective nature.

There is much to learn about the causes, nature, and containment of corrosion, but it does not follow that there is a lack of combative techniques and materials. The proper attack on an extensive or costly corrosion problem consists of an engineering study which describes in detail the technical solutions, the costs and time involved, and the mission impact. Many corrosion problems arise because of omissions in the original design where insufficient consideration may be given to corrosion control. The remainder of the initial corrosion problem arises from poor craftsmanship exercised in the surface preparation and protective coating application. Adherence to the lowest initial-cost concept may add as much as 150 percent to the lifetime cost of complicated iron and steel structures. All the lifetime costs should be studied in the initial design. Figure 2-15 illustrates the life and economics of four different paint-system cost combinations. Although the 2X method initially costs twice that of the X method, both costs are equal at 2.4 years or point A, and from that point on in time, the 2X method saves money. Points A, B, C, D, E, and F indicate break-even points for the different methods. From any of these break-even points forward in time, the more expensive initial-cost method is the less expensive life-cost method. Note point D at 3 years of life, where the X and 8X methods are equal in cost. From point D forward, the 8X method saves money. The lifetime monetary savings of the higher initial cost method are not the only benefits. During the life cycle, the higher initial cost method results in less downtime for repairs and, therefore, fewer mission capability degradations.

8X: CLASS IV SURFACE PREPARATION, ZINC RICH SILICATE, VINYL ENAMEL.
4X: CLASS III SURFACE PREPARATION, WITH ZINC CHROMATE, ALKYD ENAMEL.
2X: CLASS II SURFACE PREPARATION, WITH OIL PAINT.
 X: CLASS I SURFACE PREPARATION, WITH OIL PAINT.
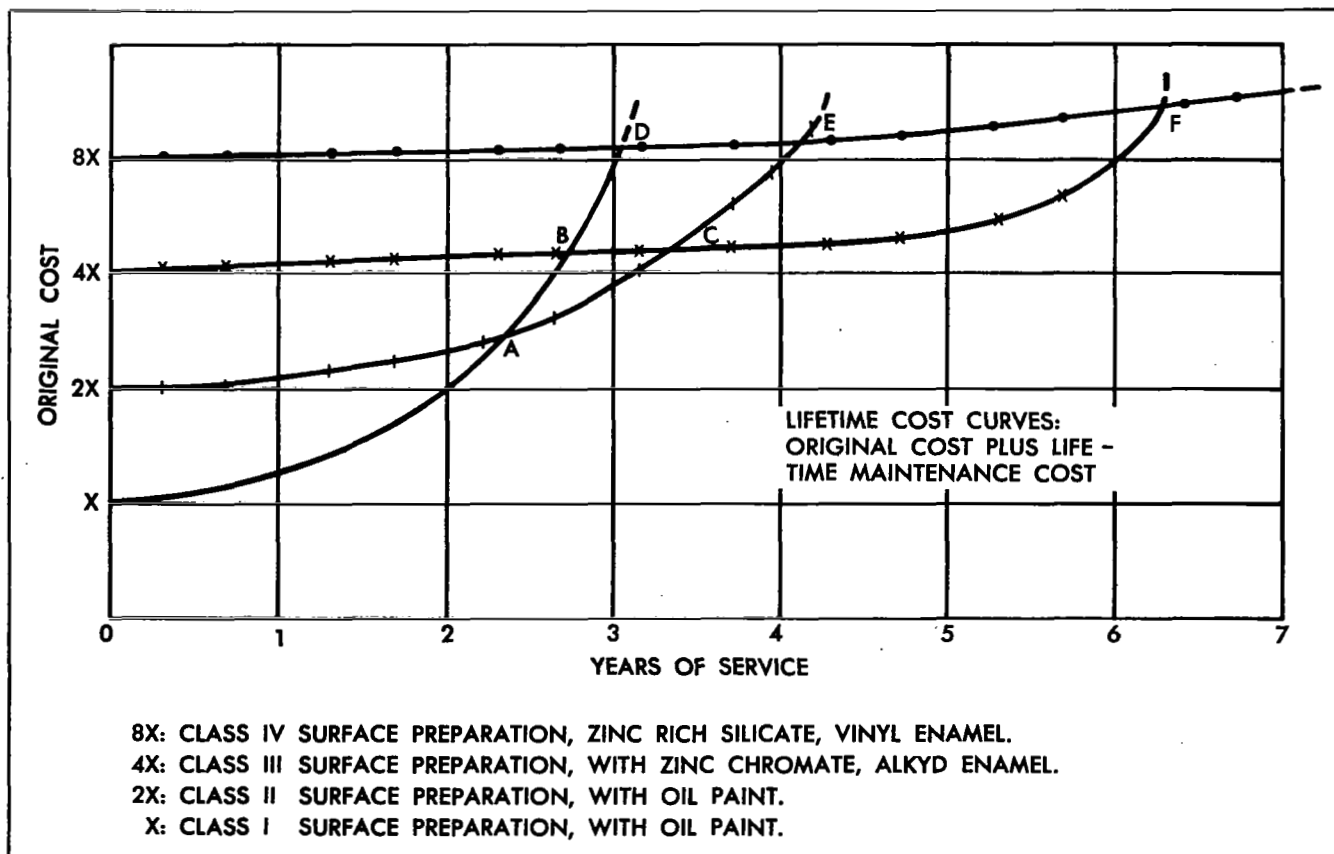
Figure 2-15. Life Vs Cost of Paint Systems on Structural Steel in Normal Environment

PART B. CORROSION CONTROL

2.7 CORROSION AT THE MSFN TRACKING STATIONS

Corrosion and its effects are of concern to the tracking stations around the world. There are no two stations with exactly the same environment; therefore, there are no exact duplications of corrosion attack among the stations. Although not all types of corrosion affect the MSFN stations, the different rates of attack for the types of corrosion that have been identified produce many variations. At Goldstone, in the high desert country of California, the corrosion rate is extremely slow. At Coopers Island in Bermuda, the rate is extremely rapid. At Bermuda, the cadmium plating on ferrous metals deteriorates in less than 3 months; some stainless steels develop corrosion problems in a few months, and some RF connectors are effective less than 6 months.

2.8 CORROSION-CONTROL CENTERS AT THE MSFN TRACKING STATIONS

It is the operation and maintenance personnel who must correct or live with the design errors in the area of corrosion. Reducing the rate of corrosion requires a scientific, yet practical program. Each tracking station should have a corrosion-control center and program with a level of activity which is governed by several vital factors:

a. Type of environment
b. Design characteristics
c. Power plant size and usage
d. Utility systems
e. Soil conditions
f. Structural materials
g. Care exercised by operation and maintenance personnel.

It is obvious the environment will play a very important role in the corrosion of structural materials because of exposure. It is equally obvious that the atmospheric environment* will have no effect on the internal corrosion rate of diesel engine coolant systems. Because of environmental and design variations, a center to control the various types of corrosion at a station must be fitted to that particular station. The different chemical tests for pH, phosphate, chlorine, potassium dichromate, etc., are described in many texts; however, the frequency of testing and treating, the reagents, the test equipment, the treatment chemicals, and the log and record requirements must be fitted to each individual station. A worthwhile

* Refer to table 2-4.

corrosion control program for a tracking station cannot be detailed from a remote location. True corrosion control at the facility demands scheduled attention to the local details such as chemical tests and treatment, spot surface preparation and spot repair painting, plotting test and treatment data, plotting surface ruptures in coating systems, monthly diagnoses, and corrosion status reports.

When a corrosion control program is initiated, several key factors must be coordinated and emphasized. These vital program requirements are as follows:

a. The continuing interest of management
b. Selection of the correct corrosion-control man
c. Adequate training
d. Time allotment
e. Required tools.

Under proper management and technical control, corrosion can be reduced, even in a harsh environment, at a manpower input of approximately one man-day per week per station. Such a program requires a corrosion-control center at each tracking station.

2.9 CORROSION-CONTROL CENTER REQUIREMENTS

2.9.1 MANPOWER

It requires only one man to make lab tests, treat with required chemicals, prepare metallic surfaces, repair paint, and maintain records.

2.9.2 INITIAL TRAINING PROGRAM

Training time will be approximately 56 hours. The classroom subjects and hours are as follows:

a. Electrochemistry of corrosion—8 hours
b. Surface preparation—4 hours
c. Paint systems—8 hours.

The laboratory facilities will include equipment, reagents, and treatment chemicals to handle all required chemical work for the entire station. Laboratory training will include:

a. Chemical tests—8 hours—which include:
  (1) pH
  (2) Chlorine
  (3) Phosphate
  (4) Potassium dichromate.

b. Resistivity of soils—8 hours

c. Surface preparation—8 hours

d. Paint application—4 hours.

2.9.3 TOOLS

Tools are required for the interested man with proper training. The type of tools needed at each station should be determined not only by the types of work but also by the volume of work; guidelines on corrosion-control tools for each tracking station follow:

a. *Steam cleaner*. Each station can make good use of a steam cleaner, and, although not all stations need the same size unit, there is justification for one size network-wide because of the required backup of parts. A steam cleaner that will boil 2 gallons of tap water into 100 pounds per square inch steam per minute would be a suitable size for each station. The steam cleaner should be trailer-mounted, self-contained with boiler, pumps, mixing box, 100 feet of hose, and a variety of nozzles. It should be equipped with a pressure gauge, safety valve, fuel adjustment, and automatic fuel shut off for flame outs, high pressure, and low water.

b. *Sandblaster*. The sandblaster should be trailer mounted for maneuverability, have a 50-pound sand capacity, work at a pressure of 100 pounds per square inch through a $\frac{1}{8}$-inch diameter nozzle, and have a minimum of 25 cubic feet of airflow per minute. The nozzle should be fitted with a remote control cutoff to permit proper control of the sand. The use of such a machine depends upon an adequate supply of air. A storage bin for maintaining dry sand is another requirement. A 500-pound capacity bin is considered adequate.

c. *Needle gun*. The great value of a needle gun is its instant readiness and ease of use when compared with a sandblaster. It is ideal for surface preparation of very limited areas that are fully accessible to the operator. However, a great many of the corrosion problem areas on the MSFN antennas are rather inaccessible to the needle gun. A corrosion-control problem warrants a needle gun and a sandblaster at each tracking station.

d. *Paint sprayer*. Most paint repair work will be the repair of small spots. This repair can be accomplished by a brush or by a completely portable, self-contained, miniature spray system including gun, paint,

and compressed air tank. In a proper corrosion control program, the repair of a 1-centimeter protective coating rupture may require a little sandblasting, a very small application of pretreatment, primer, and top coating. Very small, completely portable, and highly efficient equipment would be needed.

e. *Paints*. The various paints in the paint system on an antenna must be in storage at the station. For example, Goldstone would store MIL-P-15328, MIL-P-8585, and MIL-E-489 for the Apollo antenna. The novelty to storing this paint is the size of the containers. The maximum size should be $\frac{1}{2}$ pint cans because of the size of repair jobs and the requirement for keeping the paints fresh. Another solution would be pint spray cans of the various paints in the system. Shelf life should be estimated at 2 years unless the manufacturer states otherwise.

2.9.4 CHEMICAL LABORATORY

The requirements are as follows:

a. *Size*. The physical size need not be great. A floor space 4 feet by 6 feet can contain the storage and apparatus cabinets, the sink, etc. (All chemicals and laboratory instruments should be kept in a closed cabinet when not in use.)

b. *Cost*. The cabinets, plumbing requirements, glassware, reagents, bulk chemicals, test equipment, etc., will cost approximately $2000 per station.

c. *Lab equipment*. This includes:
   (1) pH color comparator: Taylor pH slide comparator model T-O or equal with slides ranging from 5.2—6.8 to 8.0—9.6
   (2) Na_2CrO_4 (sodium chromate) color comparator: Taylor chromate slide model N or equal
   (3) Chlorine colormeter: Taylor super chlorimeter or equal
   (4) Total hardness tester: Taylor total hardness set (ETDA method) or equal
   (5) Taylor Midget Dalite lamp or equal
   (6) Lab bench equipment
   (7) Lab glassware.

2.9.5 RECORDS

Several records should be maintained at the tracking station. These are chemical test results, treatment dosages, location and size of paint re-

pair patches, and time consumed on corrosion control. These data can indicate the effectiveness of the program to the station director. Experience has shown that once a profile of corrosion-control activity is established, the only instance in which such reports are submitted to a higher headquarters is when the program deviates from the profile for unknown reasons.

The effectiveness of a corrosion control program at any station will be in direct proportion to the director's interest. Corrosion control is not a glamorous task; it is tedious and routine. All facets of management must realize this and continually motivate the persons involved. It must also be understood that the control of corrosion at an MSFN tracking station cannot be accomplished by remote control. The effort must be from an interested, knowledgeable source at the station with general guidance and much support from an MSFN-designated corrosion headquarters center.

2.10 MSFN TRACKING STATION ENVIRONMENTS

Corrosion rates of metallic structures respond directly to the environments in which the facilities are installed. Environments must be considered primarily as climatic conditions; however, in many cases the activities of man-added contaminants to a natural environment have a heavy impact on corrosion rates. Because of the locations of MSFN tracking stations, industrial contaminants play an insignificant part in corrosion of the facilities. Again, because of various locations, the natural environments encountered are responsible for great variations in corrosion rates. The environmental impact is so great that all actions

recommended in this study are based on the environments. It is possible to define environments qualitatively—in fact, most definitions are of this type—but it was found that qualitative terminology to define environments for this study was not specific enough to be of finite value. It was necessary, therefore, to devise quantitative limits. The range of MSFN tracking station environments was stratified into four groups as shown in table 2-4. This entire study utilizes the four defined groups as the basis for all recommendations. Therefore, it is mandatory that their limits be fully understood.

A favorable environment for one activity or condition might well be considered very unfavorable for another. An environment in most cases must be defined in terms of the operation of the activity. The four MSFN tracking station environments are defined and stratified according to their degree of corrosiveness as shown in table 2-4. In this context, the facility at Bermuda is a harsh environment while the facility at Goldstone, California, is a dry environment.

At present, there is no data on the corrosion rates at the MSFN tracking station locations, but some very significant and interesting work has been done at other locations. The data was reported by the American Society for Testing Materials. (Refer to table 2-5.) Note that steel lost over 2000 times as much weight during one year at Kure Beach, N. C., as at Normal Wells, N.W.T., Canada, just below the Arctic Circle. This vividly illustrates the tremendous impact of environments on corrosion rates.

Table 2-4. MSFN Facility Environments

Wetness Rating	Environment	Physical Limits
Arid	Dry (Minimum Corrosion)	Relative Humidity—25% or less, 95% of the time. Temperature—unimportant.
Average	Normal	Relative Humidity—15—50%, 95% of the time. Temperature important above 50°F.
Damp	Humid	Relative Humidity—41—100%, 95% of the time. Temperature important above 40°F.
Sea Coast	Harsh (Maximum Corrosion)	Relative Humidity—41—100%, 95% of the time. Temperature important above 32°F. One or more saline aerations per day.

Table 2-5. Corrosiveness of Atmospheres at Test Sites Relative to That at State College, Pa.
(based on losses of two 4- by 6-inch specimens)*

Location	Type of Atmosphere	Steel		Zinc	
		Grams Avg Loss	1960-1961 Rating	Grams Avg Loss	1960-1961 Rating
1. Norman Wells, N. W. T.	Rural	0.1	0.02	0.052	0.2
2. Saskatoon, Sask.	Rural	1.4	0.2	0.074	0.2
3. Fort Clayton, C. Z.	Tropical jungle	2.8	0.4	0.266	0.8
4. Rocky Point, B. C.	Marine	4.6	0.7	0.110	0.3
5. Detroit, Mich. [1]	Urban	5.9	0.9	0.270	0.8
6. State College, Pa.	Rural	6.4	1.0	0.334	1.0
7. York Redoubt, N. S.	Marine	7.4	1.2	0.371	1.1
8. New Hampshire Coast, N. H.	Marine	9.4	1.5	0.458	1.4
9. South Bend, Pa.	Semi-rural	10.5	1.6	0.396	1.2
10. Columbus, Ohio [1]	Urban	10.9	1.7	0.468	1.4
11. New Cristobal, C. Z. [1]	Tropical marine	11.1	1.7	0.740	2.2
12. Pittsburgh, Pa. [1]	Industrial	11.4	1.8	0.512	1.5
13. London (Battersea), England [1]	Industrial	12.7	2.0	0.409	1.2
14. Miraflores, C. Z.	Tropical urban	13.2	2.1	0.334	1.0
15. Research Center, Pittsburgh, Pa.	Semi-industrial	14.0	2.2	0.488	1.5
16. Daytona Beach, Fla.	Marine	14.3	2.2	0.418	1.3
17. Cleveland, Ohio	Industrial	15.5	2.4	0.485	1.5
18. Brazos River, Tex.	Marine	17.1	2.7	0.466	1.4
19. Bayonne, N. J.	Industrial	21.6	3.4	1.020	3.1
20. Kure Beach (800-ft site), N. C.	Marine	23.2	3.6	0.640	1.9
21. Pilsey Island, England	Marine	25.8	4.0	1.058	3.2
22. London (Stratford), England	Industrial	41.3	6.5	1.608	4.8
23. Halifax, N. S. (Fed. Bldg.)	Marine industrial	46.9	7.3	2.913	8.7
24. Point Reyes, Calif.	Marine	61.0	9.5	0.338	1.0
25. Dungeness, England	Marine	97.2	15	0.768	2.3
26. Galeta Point Beach, C. Z.	Tropical marine	117.3	18	2.577	7.7
27. Kure Beach (80-ft site), N. C.	Marine	210.1	33	2.114	6.4

Note

[1] Exposure made on roof.

*Extract from *Report of Committee B-3* (Appendix II), Proceedings, American Society for Testing Materials Vol. 59 p. 200 (1959).

CHAPTER III.   THE CORROSION RESISTANCE OF METALS

INTRODUCTION

3.1   GENERAL

Each structural metal or alloy has a certain propensity to corrode in a given environment. The natural resistance to corrosion of many structural metals provides a means of reducing costs. The variation in resistance to corrosion demonstrated by the different alloys of a single metal serves to underscore the necessity of carefully selecting structural metals for MSFN tracking station facilities. Enormous quantities of data concerning the corrosion of structural metals are available as a result of industrial product development and research. The interpretation and proper application of the data determine the success of a corrosion-control program.

3.2   TECHNICAL

Once engineers and technicians become sufficiently aware of the fact that different metals and the alloys of those metals demonstrate great variations in corrosion resistance, a marked reduction in operating expense due to corrosion should take place. What may be an excellent metal with high corrosion resistance in one environment may perform very poorly in another environment. In determining what metals to use in controlling corrosion, full consideration must be given to the environment, the functional role of the materials involved, and the expected life of the structure. Such determinations cannot be made without an understanding of the tendency of metals to resist certain types of corrosion. Chapter III reviews the various alloys of aluminum, iron and steel, magnesium, nickel, and stainless steel, and emphasizes their propensities to corrode and their corrosion resistances.

PART A.   ALUMINUM

3.3   GENERAL

Bauxite, containing hydrated oxide of aluminum, is the principal aluminum ore. It is refined by treatment with caustic soda so as to precipitate hydrated alumina. Following calcination, the pure alumina, Al_2O_3, is dissolved in molten cryolite and electrolytically reduced to metallic aluminum. Minute quantities of impurities in the alumina, such as the oxides of iron and silicon, are reduced and appear in the aluminum.

The first architectural use of aluminum was as material for casting monuments and statues. The aluminum cap of the 555-foot Washington Monument is the first known use of aluminum in weather. This 100-ounce casting, the largest piece of aluminum fabricated until that time, has been examined twice: once in 1934 (after 50 years of service) and again in 1964 (80 years). The examinations confirmed good resistance to weathering as demonstrated by the legibility of the in-scription engraved on the cap in 1884. This first known use of aluminum was followed by other aluminum monuments, the best known of which are the statue of Eros in London (1893), the cast sculptures on the St. Louis courthouse (1927), and the anodized (and dyed) Navy and Marine Monument in Washington, D. C. (1933). Aluminum's resistance to atmospheric weathering plus other attributes including light weight, adequate strength, and good formability, has resulted in the extensive use of aluminum alloys, particularly in the building industry. Its ability to sustain a variety of finishes has also increased its usefulness in structures exposed to the weather.

3.4   ALLOY DESIGNATIONS

An alloy designation scheme identifies specific aluminum alloys. The system of designating wrought aluminum alloys utilizes four numbers with the first number specifying the alloy group. The system is as follows:

Alloy Number	Principal Alloying Element
1XXX*	Commercially pure Al(99 + %)
2XXX†	Copper
3XXX	Manganese
4XXX	Silicon
5XXX	Magnesium
6XXX	Magnesium + Silicon
7XXX	Zinc
8XXX	Other

Wrought Aluminum Alloy Designations

Aluminum casting alloys are not identified in the United States by a single commercial designation system. The nomenclature of cast aluminum alloys contains proprietary numbers, specification designations of the ASTM, and a three-digit code used by metal producers in the United States. In the three-digit code, the major alloying element is indicated according to the following list:

Series	Alloy Family
1 to 99	Al–Si
1XX	Al–Cu
2XX	Al–Mg
3XX	Al–Si
4XX††	Al–Mn
5XX††	Al–Ni
6XX	Al–Zn
7XX	Al–Sn

Cast Aluminum Alloy Designations

See special note re: Cast aluminum page 4-6.

3.5 HARDENING PROCESS DESIGNATIONS

To classify the various hardening processes or tempers, in 1948 the Aluminum Association assigned a designation system for wrought and cast heat-treatable alloys as well as for nonheat-treatable alloys. The system is based on heat-treatment sequences used to produce the various tempers. In this classification system, the symbol for temper designation follows the alloy number. Basic temper is identified by a letter, and subdivisions of a basic temper are identified by numbers. For example, 6061-T6 designates a heat-treatable aluminum-magnesium-silicon alloy; the T designates heat treatment to produce stable tempers; and the 6 refers to the specific sequence of treatments. Temper designations for *heat-treatable* alloys are as follows:

* Referred to as the 1000 series.
† Referred to as the 2000 series, etc.
†† No commercial alloys established as yet.

F —as fabricated, no mechanical property limits can be set

O —annealed (wrought products only), softest tempers of wrought products

W—solution heat treated, unstable temper of alloys that age at room temperature after solution heat treatment

T —heat treated to produce stable tempers other than for O. The T is always followed by one or more digits from 1 through 10 which indicate the specific sequences of treatments as follows:

Basic Tempers

Numbers Following T Indicate Specific Sequences of Treatments

T1—naturally aged to a substantially stable condition

T2—annealed (cast products only) to improve dimensional stability

T3—solution heat treated, cold worked, and naturally aged to a substantially stable condition

T4—solution heat treated and naturally aged to a substantially stable condition

T5—artificially aged only

T6—solution heat treated and artifically aged

T7—solution heat treated, averaged, and then stabilized.

The temper designations for nonheat-treatable alloys consist of a letter for basic temper and digits for divisions of that temper. For example, 5056-H18 indicates a nonheat-treatable aluminum-magnesium alloy; the H1 signifies that it is strain hardened; and the 8 refers to the degree of hardening. The temper designations for strain-hardened *(nonheat-treatable)* alloys are as follows:

F—as fabricated, no mechanical property limits can be set

O—annealed and recrystallized, lowest strength, greatest ductility

H1—strain hardened for greater strength than O

H2—strain hardened and partially annealed to control exact hardness

H3—strain hardened and stabilized to increase ductility and stabilize mechanical properties

H112—strain hardened during fabrication, no control over excessive hardening, but tested to meet minimum properties

H321—strain hardened during fabrication, but temper was controlled by hot and cold working

H323 and H343—strain-hardened and corrosion-resistant tempers for aluminum and magnesium alloys.

At least 99 percent of all aluminum used commercially is as an alloy since pure aluminum has little structural strength. For example, 1199-0, which is 99.99 percent pure aluminum, has a tensile strength of 6500 pounds per square inch and a yield strength (0.2 percent offset) of 1500 pounds per square inch; however, 2024-T86, which contains 93.4 percent Al, 4.5 percent Cu, 0.6 percent Mn, and 1.5 percent Mg has a tensile strength of 75,000 pounds per square inch and a yield strength of 71,000 pounds per square inch. The combinations of aluminum-alloy tempers and structural shapes provide a wide range of choices for the engineer. For example, there are almost 200 alloy and temper designations for structural aluminum commercial production. Table 3-1 lists several specific aluminum alloys and their characteristics; this list is by no means complete, but it is a sample of some well known and MSFN utilized aluminum alloys.

3.6 COMMENTS ON ALUMINUM ALLOYS

There is no element that is completely soluble in aluminum. Several elements are sufficiently soluble to cause important changes in the strength, and heat- and corrosion-resistant properties of the resultant aluminum alloy. These alloying elements are Ag, Cu, Ge, Li, Mg, Si, and Zn. The formation of solid-solution alloys strengthens aluminum. Aluminum also readily forms insoluble phases with metallic elements such as B, Ga, Mn, Ni, Ti, and Zr, which may increase strength and hardness at high temperatures and reduce ingot cracking. An outstanding characteristic of aluminum is its ability to form so many useful alloys with other metals.* Notes on several aluminum alloy families or series are provided in the following paragraphs.

* Refer to QQ-A-250, *General Specifications for Aluminum Alloy Plate and Sheet.*

3.6.1 ALUMINUM–COPPER ALLOYS, THE 2000 SERIES

The 2000 series alloys, primarily in the wrought form, tempered as fabricated or heat treated, have accounted for the growth of the aluminum industry more than any other alloy-temper combination.. The copper content of this series can be as high as 10 percent. Solution treatment followed by aging results in increased strength and hardness and a decrease in elongation. Corrosion resistance to NaCl solution by intermittent spraying is poor. The 2000 series is fabricated as sheet and plate; wire, rod, and bar; extruded shapes; and most structural forms.

3.6.2 ALUMINUM–MAGNESIUM ALLOYS, THE 5000 SERIES

Alloys in the 5000 series, primarily in the wrought form, are being utilized in increasing frequency for structural work. They have high strength without heat treatment, good weldability, and are resistant to corrosion. The addition of as much as 0.75 percent Mn and some Zn for other alloy property gains has little effect on this alloy's resistance to corrosion. Alloys in the 5000 series are fabricated in the form of sheets and plates, primarily for finishing and decorative purposes.

3.6.3 ALUMINUM–MAGNESIUM SILICIDE ALLOYS, THE 6000 SERIES

Alloys in this series (Al–Mg_2Si) are generally used in the wrought form; they possess high strength, ductility, and resistance to corrosion. The 6000 series alloys are fabricated primarily for structural purposes.

3.6.4 ALUMINUM–MANGANESE ALLOYS, THE 3000 SERIES

Alloy 3003 is the first and only currently used wrought Al–Mn alloy. The Al–Mn alloys have poor casting characteristics but good resistance to corrosion. Minor additions of Mn have significant metallurgical effects on Al alloy. The 3000 series is fabricated in all forms, primarily for structural, decorative, and finishing purposes.

3.6.5 ALUMINUM–SILICON ALLOYS, THE 4000 SERIES

The wrought Al alloys containing Si also contain other alloying elements such as Cu, Zn, and Mg. The addition of silicon results in significant improvements in its casting characteristics and corrosion resistance. The yield strength of modified sand castings varies from 10,000 pounds per square inch (with 8 percent Si) to 12,000 pounds per square inch (with 14 percent Si). The tensile strength of chill-cast alloy with 8 percent Si is approximately 22,000 pounds per square inch. The

Table 3-1. Characteristics of Various Aluminum Alloys

Alloy & Temper Designation	Nominal Composition %	Hardening Process	Tensile Strength lb/in²	Yield Strength lb/in²	Elongation in 2 Inches, %	Endurance Limit (5x10⁸ cycles) lb/in²	Typical Applications
Wrought Alloys							
1100-H18	Commercial purity	Strain hardened	24,000	22,000	5	9,000	Pure aluminum
Alclad 2024-T3 [1]	4.5 Cu, 0.6 Mn, 1.5 Mg	Heat treatable	70,000	50,000	18	20,000	Flat sheet
Alclad 2024-T4	4.5 Cu, 0.6 Mn, 1.5 Mg	Heat treatable	65,000	46,000	10	—	Tube & pipe
Alclad 2219-T62 [1]	6.3 Cu, 0.3 Mn	Heat treatable	60,000	42,000	10	15,000	Sheet & plate
6061-T6	1.0 Mn, 0.7 Fe, 0.6 Si, 0.25 Cu, 0.20 Cr	Heat treatable	38,000	35,000	4	—	Structural shapes
6262-T9	0.6 Si, 0.25 Cu, 1.0 Mg, 0.09 Gr	Heat treatable	58,000	55,000	10	13,000	Structural
7076-T61	0.6 Cu, 0.5 Mn, 1.6 Mg, 7.5 Zn	Heat treatable	74,000	68,000	14	—	High strength
5154-H34	3.5 Mg, 0.25 Cr	Strain hardened	42,000	33,000	13	19,000	General purpose
5457-0	0.30 Mn, 1.0 Mg	Annealed	19,000	7,000	22	—	Finishing & decorative
3004-H38	1.2 Mn, 1.0 Mg	Strain hardened	41,000	36,000	5	18,000	Sheet & plate
Cast Alloys							
B195-T6	4.5 Cu, 2.5 Si	Heat treatable	36,000	24,000	5	7,500	Structural
356-T6	0.3 Cu, 7.0 Si	Heat treatable	36,000	24,000	3.5	8,500	Structural
355-T71	1.3 Cu, 5.0 Si	Heat treatable	35,000	29,000	3.5	10,000	Aircraft & structural

Note

[1] The aluminum industry makes approximately 90 alloy and heat-treatable temper combinations for the fabrication of aluminum sheet and plate.

4000 series nonheat-treatable wrought alloys are fabricated primarily as welding wire and other wire products. The aluminum-silicon casting alloys (the 3XX series) have broad structural applications.

3.6.6 ALUMINUM–TIN ALLOYS, THE 7XX CASTING SERIES

Tin is added to wrought alloys in small amounts (0.03 to 0.05 percent). Large amounts of tin, as much as 25 percent, are added to casting alloys. The addition of tin results in augmented strength and resistance to corrosion. The 7XX series is used primarily in the manufacture of sleeve bearings.

3.6.7 ALUMINUM–ZINC ALLOYS, THE 7000 SERIES

The addition of zinc alone to aluminum results in the susceptibility to hot cracking of cast alloys and the susceptibility to stress-corrosion cracking of wrought alloys. However, when copper or magnesium is the alloying agent, considerable increase in strength is achieved without the aforementioned weaknesses. The 7000 series is fabri-

cated in most structural forms; they are used primarily in aircraft because of their high strength. One cast form of Al-Zn, alloy B605, containing 5.5 percent Zn, is used for the cathodic protection of steel structures subject to the corrosive attack of sea water.

3.7 CORROSION OF ALUMINUM

The corrosion resistance of aluminum is controlled to a considerable extent by tightly adherent, invisible, oxide films (Al_2O_3) on the surface of the metal. An oxide film starts to form instantaneously on an aluminum surface exposed to air or to oxygen. The oxide film is extremely thin, but it is so effective in resisting corrosion that processing methods such as anodizing have been developed to increase its thickness. When the film is broken, aluminum usually corrodes as a result of electrochemical deterioration as do other structural metals. Specific factors that promote the corrosion of aluminum are as follows:

a. The composition of the microconstituents in aluminum alloys, their location, quantity, continuity, and potential, with relation to the aluminum solid solutions, affects the amount and distribution of corrosion. For example, the iron in commercially pure aluminum is cathodic to the aluminum.

b. Metallurgical treatments to achieve prescribed strength and working properties of the alloy can have a great impact on corrosion rates. Heat treatment and cold working may produce residual stresses which can lead to stress-corrosion cracking. Proper design or subsequent thermal or mechanical stress relief operations can largely obviate such problems.

c. Corrosion attacks centered around scratches and abrasions result from differences in potential around the broken Al_2O_3 film.

d. Differences in electrolyte concentrations and oxygen concentrations promote corrosion. Coating the surfaces of joints with a suitable primer (such as zinc chromate) will protect against attack caused by such differential concentrations, unless the electrolyte contains NaCl. In harsh environments, caulking, in addition to priming, should be applied between joint surfaces.

e. The protective Al_2O_3 film is affected by pH ranges. The film is stable in the pH range from 4.5 to 8.5. As a general rule, the film is readily attacked in strongly acid or alkaline solutions.

f. Temperature ranges common to MSFN facilities do not significantly affect the corrosion of aluminum.

g. Various types of corrosion attack aluminum alloys, but it appears that exfoliation and galvanic corrosion are the most serious forms for the MSFN tracking station facilities.

(1) Exfoliation corrosion occurs principally in sheet and plate sections and follows a linear path parallel to the grain direction. Common locations for the initiation of this type of corrosion are the countersunk areas of fastener holes or the unprotected ends of parts where end grain is exposed. Grain boundaries are anodic to the grains and convert to corrosion products. Because the products of corrosion occupy more space than the original metal, they exert extreme pressure on the surrounding metal with subsequent expansion within the corroded area. Corrosion then proceeds in parallel or lamellar paths along the grain boundaries and destroys the structural integrity of the aluminum. The greatest danger from this form of corrosion is the extensive damage that can exist in the metal without breaking through the surface. Except for a swelling caused by the underlying products of corrosion, the surface may appear intact and in excellent condition. Corrosion engineers and investigators consider lamellar damage to be a form of stress corrosion aggravated by the wedging action of corrosion products.

(2) Galvanic corrosion is a prime cause of concern with aluminum used at MSFN tracking station facilities. The potentials of the galvanic series, the electromotive series, and other such guides can only indicate the possibility of galvanic corrosion; they do not specify the magnitude of corrosion. To determine the magnitude of the corrosion, the overall electrical resistance in the galvanic circuit and other features, in addition to the potential difference, must be known. One of the most probable locations for galvanic attack is the juncture of two metals, particularly pins, fasteners, nuts, bolts, or rivets. *In general, the anode corrodes more rapidly when the area of the anodic metal is small com-*

pared with the area of the cathodic metal. Thus, rivets should not be anodic to the objects they join. Because of the high conductivity of saline electrolytes, galvanic effects caused by contact between dissimilar metals are likely to be more pronounced in harsh environments than in areas without saline aerations. Metallic combinations that result in galvanic attacks on aluminum are as follows:

a. Aluminum alloy and stainless steel couples result usually in selective attack on the aluminum alloy. The extent of such damage will depend on the particular aluminum alloy involved. In general, corrosion from this source is not particularly rapid. The effects of polarization account for the fact that stainless steel causes less galvanic current flow from anodic regions on aluminum than is indicated by electrode potentials.*

b. Contact between aluminum alloys and unalloyed steel normally results in a more pronounced selective attack on the aluminum alloy than is the case with stainless steel. From table 3-2 it can be seen that the potential between aluminum alloy 7075 and mild steel is —0.23 volts, which indicates a tendency toward galvanic corrosion.

* Satisfactory results have been obtained with 2024 aluminum and stainless steel. In harsh environments, however, the 2000 series of Al alloys is corrosion prone.

Table 3-2. Solution Potentials Emphasizing Aluminum

Metal or Alloy [1]	Potential, v, 0.1N calomel scale [2]
Magnesium	−1.73
Zinc	−1.10
B605	−1.06
A612	−0.99
7-72, Alclad 3003, Alclad 6061, Alclad 7075	−0.96
X7005-T6, -T63; 7039-T6, -T63	−0.93 to −0.96*
220-T4	−0.92
2056, 7079-T6, 5456, 5083, 214, 218	−0.87
5154, 5454	−0.86
5052, 5086	−0.85
3004, 1060, 5050, 7075-T73	−0.84
1100, 3003, 6151, 6053, 6061-T6, 6063, Alclad 2014, Alclad 2024	−0.83
13, 43, Cadmium	−0.82
7075-T6, 7178-T6	−0.81 to −0.85*
356-T6, 360	−0.81
2024-T81, 6061-T4	−0.80
355-T6	−0.79
2219-T6, -T8	−0.79 to −0.82*
2014-T6, 750-T4	−0.78
108-F	−0.77
380-F, 319-F, 333-F	−0.75
195-T6	−0.73
B195-T6	−0.72
2014-T4, 2017-T4, 2024-T3, -T4	−0.68 to −0.70*
2219-T3, -T4	−0.63 to −0.65*
Mild steel	−0.58
Lead	−0.55
Tin	−0.49
Copper	−0.20
Bismuth	−0.18
Stainless Steel (series 300, type 430)	−0.09
Silver	−0.08
Nickel	−0.07
Chromium	−0.40 to +0.18*

Notes
[1] The potential of all tempers is the same unless temper is designated.
[2] Measured in an aqueous solution of 53 g per liter NaCl +3 g per liter H_2O_2 at 25 C.
*The potential varies with quenching rate.

c.
4. Aluminum alloys in contact with copper generally lead to extremely pronounced selective attack of the aluminum alloy. For structures which are exposed to the atmosphere, complete electrical insulation of the aluminum from the copper is the best method of preventing galvanic action, but this is not always practical. A heavy cadmium coating on the copper prevents galvanic action (as long as the coating lasts), since cadmium has a potential similar to many aluminum alloys.

d **5.** Copper alloys, such as the various brasses and bronzes or nickel alloys, (such as copper-nickel) all behave similarly to copper when in contact with aluminum alloys.

e **6.** Only magnesium and zinc are anodic to aluminum alloys in most environments. When a zinc-aluminum alloy couple is exposed to a harsh environment, the zinc alloy provides cathodic protection to the adjacent aluminum alloy member. As a rule, when a magnesium-aluminum alloy couple is exposed, the magnesium provides cathodic protection for the aluminum alloy, but in some instances overprotection of the aluminum cathode may occur, causing cathodic corrosion of the aluminum alloy. Magnesium-base alloys are the only structural alloys which have been found to cause this special cathodic corrosion.

In table 2-1 the position of aluminum is shown in the electromotive series; in table 2-2 the positions of aluminum and its alloys are shown in the galvanic series. Table 3-2 indicates the positions of aluminum alloys as determined by solution potential. Such tables are of great value to design and corrosion engineers; much of the total corrosion problem could be solved through use of this information. *As a general rule contacting metals will experience less corrosion attack when the smaller part is cathodic to the larger.* The potential difference between any two metals used in the MSFN station facilities should never exceed 0.25 volts. The emf between any two metals may be computed when certain data are known. See discussion on emf computations, page 2-13.

3.8 CORROSION CONTROL FOR ALUMINUM STRUCTURAL ALLOYS

The large variety of methods currently available to control the corrosion of aluminum alloys makes these alloys highly desirable as structural metals. All the following methods of corrosion control employ the fundamentals outlined in Chapter II, page 2-4.

a. Anodize the alloy surface to create a thicker coating of oxide. In addition to being considerably more resistant to corrosion, such an oxide coating is also more resistant to abrasion. (See figure 3-1 for a magnified view of an anodized surface and schematic of the anodic structure.) Additional protection is gained by sealing and painting the anodized surface. *higher potential*

b. Metal clad the surface with ~~high-purity~~ aluminum; ~~high-purity aluminum is extremely corrosion-resistant and~~ *the aluminum will then be* anodic to the base metal. The thickness of the protective coatings usually ranges from 5 to 10 percent of the base metal thickness. (See figure 3-2, a cross section of clad aluminum sheet.)

c. Use anodic sacrificial metals or alloys to cathodically protect the structural metals.

d. Build structures completely of aluminum to eliminate galvanic couples.

e. Metal spray with high-purity aluminum and seal with a wash primer and vinyl paint. (See figures 5-2 and 5-3.)

3.9 USES OF ALUMINUM FOR MSFN TRACKING STATION FACILITIES

The qualities, strength, and resultant service life of aluminum in its various applications at the MSFN tracking stations can hardly be considered as imponderables. The position of aluminum and its alloys in the electromotive series, in the galvanic series, and in the solution potential series leaves no doubt as to the probable results if, for example, aluminum and copper are joined in an uninsulated metallic couple and are subjected to a harsh environment. On the other hand, because of some highly effective corrosion protection techniques, aluminum should be considered as a highly desirable structural metal. The most desirable environment for the use of aluminum is a dry one. For use in normal, humid, and harsh environments, corrosion-control measures should be incorporated in the design of the antenna and supporting structure.

3.10 COMPARISON OF COSTS

To illustrate the comparative costs of aluminum and steel structures, it was necessary to compare the initial and maintenance costs of bridges because such data could not be found for MSFN tracking station structures. Two aluminum-plate, riveted-girder bridges on the Long Island Expressway were considered. These bridges weigh 14 pounds per square foot, and the designer esti-

498 BILLION PORES
PER SQUARE INCH

HEXAGONAL CELLS

120 Å

POROUS LAYER

BARRIER LAYER

METAL

MAGNIFICATION 75,000X

MAGNIFICATION 1,000X
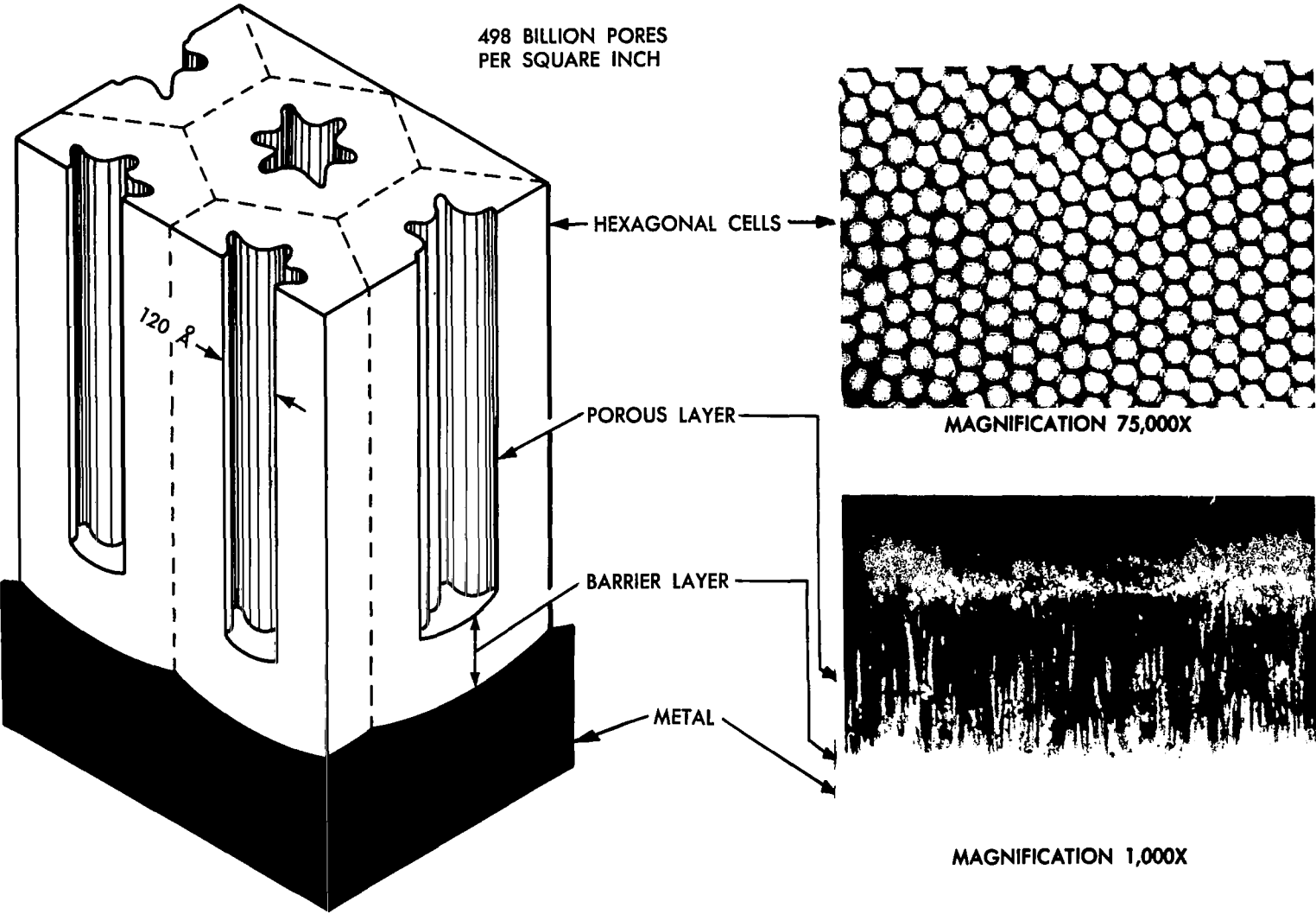
Figure 3-1.   Structure of Porous Anodic Coating on Aluminum

MOUNTING MATERIAL

ALUMINUM CLAD (HIGH PURITY 1050)

STRUCTURAL ALUMINUM (ALLOY 2024-T3)

ALUMINUM CLAD (HIGH PURITY 1050)

MOUNTING MATERIAL
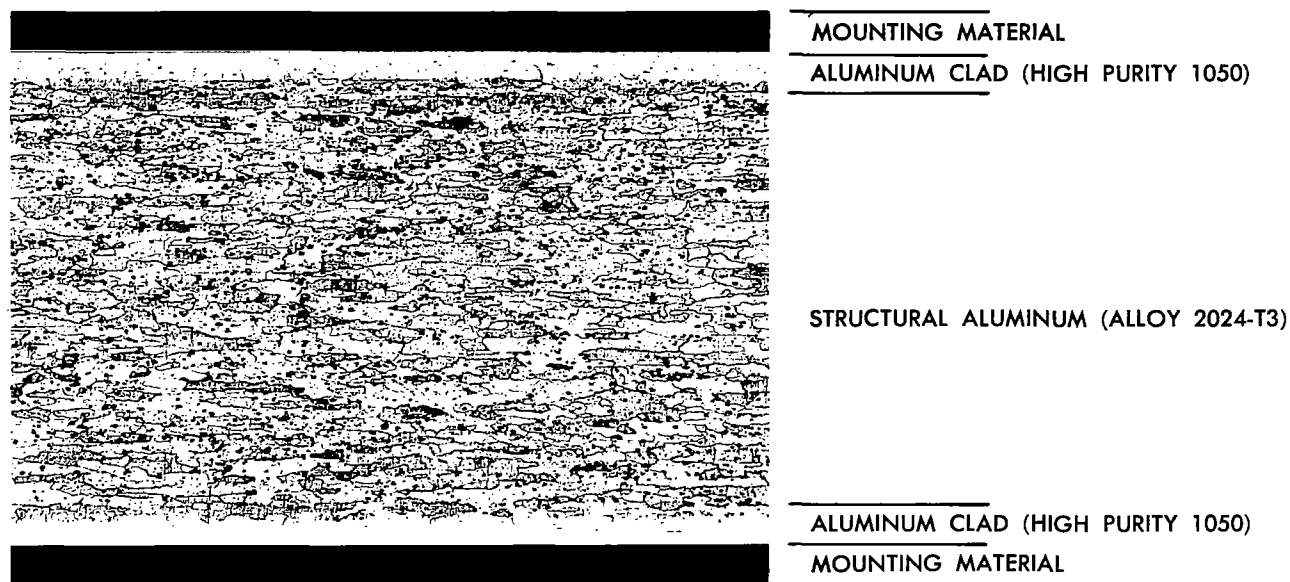
Figure 3-2.   Alclad Aluminum (125 Diameter Magnification)

mates that similar steel structures would weigh 35 pounds per square foot. The painting costs of similar steel bridges were projected from page 220, Volume I of the *Steel Structures Painting Manual.* Both steel and aluminum bridge lives were taken as 50 years, with cleaning and painting of the steel bridge at 7, 14, 21, 28, 35, and 42 years. Table 3-3 gives the cost data which is based on the survey year of 1948 and, therefore, requires adjustment by labor and material cost indexes for any year in the future. Salvage price of the steel at the end of the period would be $27.50 per ton for steel and $360 for aluminum.

The break-even point occurs at about 28 years of life, which is a longer life than projected for most MSFN tracking station structures. It is estimated that the MSFN painting cycle on a steel

Table 3-3.   Aluminum and Steel Cost Comparison

	Aluminum	Steel
Initial Cost	$136,000	$111,500
Maintenance (painting)	—	29,254
Life Cost	$136,000	$140,754

structure would be every 3 years in a harsh environment. It is also estimated that the original painting of an aluminum structure would endure for 6 years in a harsh environment and would thus create much less mission degradation. The largest observable factor would be the increased mission capability of the aluminum structure with some minor savings in life cost.

PART B.   IRONS AND STEELS

The corrosion-resistant characteristics of high-alloy irons and steels (such as the chromium-nickel steels) are detailed in Part E of this chapter. Part B describes the corrosion resistance of low-alloy, wrought, and cast irons and steels. These ferrous metals constitute the greatest percentage of most machines and structures; therefore, it is important to describe their respective corrosion-resistant

properties and the treatments necessary to enhance their performance in this regard.

3.11   FERROUS METALS

3.11.1   CAST IRONS

Cast iron is used in great quantities for many functions. It contains from 3 to 3.5 percent carbon

plus silicon and other elements. Structurally, it includes free carbon (in the form of graphite), iron carbide, and iron. The free carbon makes gray cast iron susceptible to graphite corrosion in harsh environments where saline wetting occurs. White cast iron, on the contrary, is considerably less affected by corrosion because its carbon content is almost totally in the form of carbide. For additional details on cast irons, refer to QQ-I-666, MIL-I-24137, MIL-I-18397, and MIL-I-22243.

3.11.2 CARBON STEELS

The corrosion resistance of carbon steel approximates that of white cast iron. The free carbon in steel has much more effect on its structural properties than on its corrosion resistance. For the chemical composition and hardenability of steel, refer to Federal STD 66.

Previous to 1941, many steel purchasers ordered steel by specifying the chemical compositions and quality requirements. Such a system generated a nearly endless number of combinations, many of which were very similar in composition. A series of studies indicated that a concentration on fewer grades would generate more opportunities to advance both technology and the manufacturing process. The general acceptance and use of the 1941 standards have indicated that they have successfully replaced the compositions previously used.

These steels, called carbon steels, are identified by a code which uses letters and numbers. For example, a capital letter prefix "B" indicates acid Bessemer steel; "L" within the grade number indicates leaded steels. Numbers indicate the grades of steel by chemical composition. A series of four numerals designates the composition of carbon steel; the last two numerals show the approximate middle of the carbon range. In grade 1045, the 45 indicates the percentage of carbon range of the steel is between 0.43 and 0.50 percent. The first two numbers of the four-numeral series of various grades of carbon steel specify other chemistry and processing. For example:

10XX—Nonresulphurized carbon steel grades.

11XX—Resulphurized carbon steel grades.

12XX—Rephosphorized and resulphurized carbon steel grades.

Standard steels of interest to the MSFN can be found in table 3-4.

3.11.3 HIGH-SILICON IRONS

The high-silicon iron alloys consist of approximately 0.85 percent carbon, 14.5 percent silicon, and various percentages of molybdenum and manganese. Such alloys show good resistance to corrosion at elevated temperatures. High-silicon iron alloys are a form of cast iron; they lack ductility and are susceptible to mechanical and thermal shock.

3.11.4 COPPER-BEARING STEEL

Small amounts of copper (up to 0.2 percent) improve the atmospheric corrosion resistance of steel. However, this does not hold true if the steel is used underground or immersed in water. Incorporating up to 0.1 percent phosphorus in copper-bearing steel improves its atmospheric corrosion resistance.

3.11.5 WROUGHT IRON

Wrought iron is a commercial iron which has slag fibers or iron silicate entrained in its matrix.

Table 3-4. Characteristics of Iron-carbon Alloys

	Tensile strength lb/in²	Yield strength lb/in²	Elongation in 2 inches, %
Ferritic gray cast iron	25,000	—	0.5
Pearlitic gray cast iron	45,000	—	0.5
Nodular cast iron	80,000	50,000	5.0
Malleable cast iron	55,000	35,000	18.0
Cast steel (as cast)	74,000	34,000	19.0
Cast steel (normalized)	76,000	38,000	24.0
Machine steel, 0.2% C	50,000	27,000	35.0
Hardened and tempered 0.45% C steel	100,000	65,000	28.0
Wrought iron	50,000	30,000	30.0
Ingot iron	45,000	30,000	40.0
Cold drawn 0.80% C steel	200,000	150,000	5.0
Spheroidized 1.0% C steel	80,000	45,000	30.0
Hardened and tempered 1.0% C steel	250,000	200,000	1.0

The iron silicate confers on wrought iron some of its corrosion resistance. Wrought iron is used primarily in piping.

3.11.6 LOW-ALLOY STEELS

Certain steels are called low-alloy types because the sum of the alloying elements does not exceed 5 percent. For example, one typical low-alloy steel contains 2 percent chromium and 0.5 percent molybdenum. There are other chromium-molybdenum combinations which have enhanced corrosion and heat resistance. As a general rule, these steels are not as corrosion resistant as the stainless steels.

3.11.7 HIGH-STRENGTH LOW-ALLOY STEELS

A relatively new development in structural steel, high-strength low-alloy steel is a composition that requires no protective coating because in the presence of minute quantities of atmospheric sulfur compounds it forms a thin adherent protective oxide which resists further corrosion. Generation of the oxide coating results in its characteristic reddish brown color. This maintenance-free steel is effective in rural, industrial, and moderately varied environments for buildings, bridges, and transmission towers.*

3.11.8 CHARACTERISTICS OF IRON-CARBON ALLOYS

Refer to table 3-4.

3.12 SURFACE TREATMENTS FOR IRONS AND STEELS

Surface treatment of iron and steel to improve corrosion resistance is a highly developed science. It is well established that if the appropriate techniques are employed and good craftsmanship is practiced, the treated surfaces will perform as specified. Several of the corrosion-retarding treatments or surfacing processes follow.

3.12.1 ZINC COATING

Zinc coating can be affixed to many irons and steels and is widely used for corrosion control of ferrous metals. Zinc provides both a mechanical barrier and a sacrificial type of corrosion protection. It is considered to have excellent corrosion resistance in humid and harsh environments and is relatively inexpensive. A zinc coating can be applied by hot-dip galvanizing, electrogalvanizing, sherardizing, and metal spraying. For details of the electroplating of zinc and hot-dip galvanizing, refer to Part B of Chapter V and QQ-S-775. For metallizing (flame spraying of metal), refer to

* Refer to paragraph 2.6.

Part C of Chapter V and MIL-M-6874 plus several changes, and MIL-M-3800.

3.12.2 BLACK OXIDE COATING

A black oxide coating can be uniformly applied to ferrous metals by several means. In a typical process the ferrous metal is heated in a carburizing box to 1200°F for 90 minutes and is then quenched in oil. Another process utilizes a 40 percent solution of sodium hydroxide at 250°F in the presence of 5 percent sodium nitrate. The black oxide coating gives some corrosion control in dry and normal environments and is used for its decorative quality. For details, refer to MIL-C-13924.

3.12.3 CADMIUM PLATING

Cadmium plating is used extensively, especially for hardware such as nuts, bolts, washers, and hinges. Depending on the treatment, articles can assume hues of silvery white, clear, golden, black, and other colors. Cadmium plating is reported to have fair corrosion resistance but only after receiving a supplementary chromate treatment. Other types of cadmium plating serve as an effective paint base. It can be used to plate stainless steel to prevent galvanic action between stainless steel and aluminum. For additional details, refer to QQ-P-416. Cadmium plating does not do well in harsh environments.

3.12.4 METALLIZING (FLAME SPRAYING)

Metallizing or flame spraying is a process in which the plating metal is melted, atomized, and sprayed in the molten state onto the base metal. Almost any metal that can be powdered or made into wire can be flame sprayed. The corrosion resistance of many of the flame-sprayed metals is impressive, especially when the coating is sealed. To seal a sprayed coating, the metal is primed with a wash primer and then is top coated with a quality paint such as those incorporating vinyl chloride. One great advantage of metallizing is its ease of use in the field. For details, refer to Part C of Chapter V, MIL-M-6874 and MIL-M-3800.

3.12.5 LIGHT PHOSPHATE COATINGS

Light phosphate coatings can be generated uniformly on all compositions of steel. The coatings improve the corrosion resistance of all types of ferrous metals by serving as an excellent paint base for primers and enamels. There are three types of light phosphate coatings in current use: a zinc phosphate system, an iron phosphate system, and a system which requires a wash primer pretreatment. The application processes for all three types of coating include parkerizing (a proprietary process) and bonderizing. For details, refer to TT-C-490.

3.12.6 HEAVY PHOSPHATE APPLICATIONS

Heavy phosphate applications serve as uniform films over low- and medium-alloy steels. The heavy coating provides corrosion and abrasion resistance. The coating ranges in color from gray to black. There are two different types with several classes in each type to meet functional requirements. For details, refer to MIL-P-16232.

3.12.7 NICKEL COATING

Nickel coatings can be applied to the base metal either in hard or soft coatings and in various thicknesses. Corrosion resistance is directly proportional to the thickness of the coating. However, as indicated by its position in the galvanic series, nickel plating does not give cathodic protection to ferrous metals. Nickel coatings range in color from light to dull grey somewhat similar to stainless steel. Nickel coatings are often plated over copper to improve adhesion. There are two classes and many types of plating in current use. The thickness of copper-nickel coatings ranges from 0.0001 to 0.0002 inches. For details of electrodeposited nickel, refer to QQ-N-290.

3.12.8 ELECTROLESS NICKEL PLATING

Electroless nickel plating can be uniformly deposited in all areas without buildup on edges. Corrosion resistance is good for coatings greater than 0.0001 inch in thickness; its color is similar to stainless steel. Receptive base metals include steel, aluminum, and its alloys, copper-, nickel-, and cobalt-based alloys. Nickel plating is especially desirable where assembly tolerances require uniformity. The coating thickness ranges from 0.0005 to 0.001 or more inches. There are two classes in current use. For details, refer to MIL-C-26074.

3.12.9 LEAD COATINGS

Lead coatings are resistant to some types of corrosion, but, because of the pinholes that remain in the coating, lead is difficult to apply either by hot dipping or by electroplating. Hot-dipped lead sheets are called terne plate. The coating consists of an 80:20 mixture of lead and tin and is used for outdoor exposure, principally in industrial atmospheres.

3.12.10 TIN PLATING

Tin plating is rarely used for atmospheric protection because tin is cathodic to iron and pinholes readily.

3.12.11 COPPER PLATING

Copper is electroplated onto iron and serves as an effective base for Ni and Cr electroplated coatings.

3.12.12 ALUMINUM COATING

An effective aluminum coating can be applied to steel by immersing the steel in molten pure aluminum. The coat acts as a mechanical barrier and also serves as a cathodic protective layer. (See figure 3-3, depicting the boundary of hot-dipped aluminum on steel plate.)

Steel can also be electroplated with aluminum to produce a film which also acts as a mechanical barrier and a cathodic protective layer. (See figure 3-4, depicting the boundary of an electroplated aluminum coating on steel.)

MOUNTING MATERIAL

HOT-DIP ALUMINUM, ALLOY 4043 WITH 5% SILICON

Al/Fe INTERFACIAL LAYER
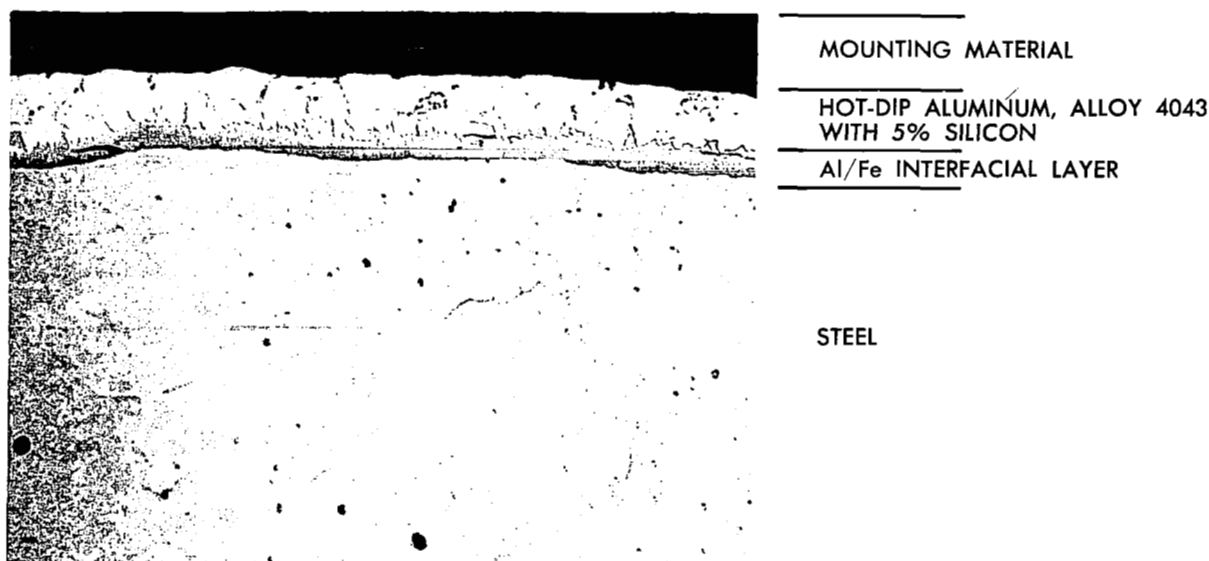
STEEL

Figure 3-3. Hot-dip Aluminum on Steel (250 Diameter Magnification)

MOUNTING MATERIAL

ELECTROPLATED ALUMINUM① COATING
SHOWING NO INFERFACIAL LAYER
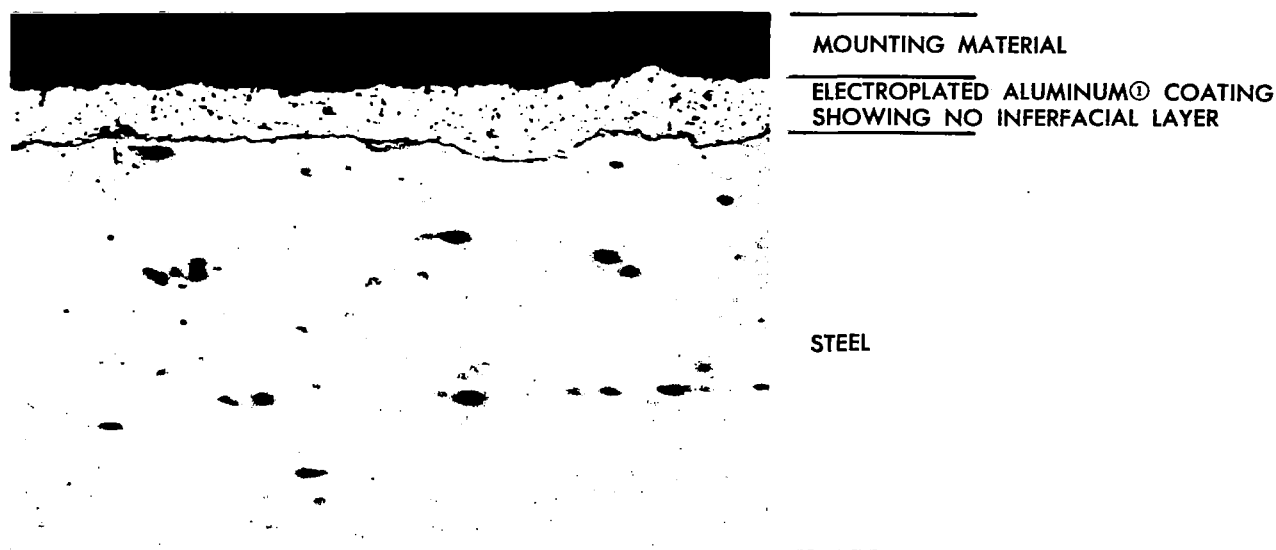
STEEL

Figure 3-4. Electroplated Aluminum on Steel (500 Diameter Magnification)

Note

Many ferrous metal alloys can be clad with thin sheets of a corrosion-resistant metal such as high-purity aluminum. For details, refer to corrosion control for aluminum structural alloys, paragraph 3.8.b.

3.12.13 PASSIVATION

Passivation does not add any metallic coating. Passivation with nitric acid assists in the re-moval of foreign substances and contaminants from the surface of stainless steels and allows the surface to oxidize naturally. Corrosion resistance is improved, but there is no change in the appearance of the steel surface. For details, refer to MIL-S-5002.

Note

MIL-T-704, the *Treatment and Painting of Material*, contains much valuable information on surface treatment for corrosion protection.

PART C. MAGNESIUM

Magnesium, derived from sea water, is a "modern" metal that has only recently made its entry into the structural field. Sea water, which contains approximately 0.13 percent magnesium, is forced into large settling tanks and mixed with lime. The calcium in the lime replaces the magnesium in the sea water; magnesium settles as insoluble magnesium hydroxide. The magnesium hydroxide is then filtered and treated with HCl. The $MgCl_2$, produced by the reaction of $Mg(OH)_2$ with HCl, is dried into a powder and fed to electrolytic cells. The final products are metallic magnesium and chlorine gas. When the metal is alloyed and formed into structural members, it is very light in weight, but possesses a high strength-to-weight ratio. Magnesium, having a specific gravity of 1.74, is the lightest of all the commonly used structural metals. The light weight of magnesium is readily dramatized by comparing magnesium and other metals in a weight ratio chart. Refer to table 3-5.

Table 3-5. Magnesium Weight Ratios

Metal	Weight Ratio	lbs/cu ft
Magnesium	1	112
Aluminum	1.5	175
Zinc	3.9	443
Cast Iron	4	450
Steel	4.4	493
Copper & Nickel	5	556
Lead	6.3	706

3.13 CHARACTERISTICS OF MAGNESIUM

   a. Extremely light

   b. Easy to machine

   c. Adaptable to coatings

   d. Adaptable to extruding, rolling, drawing, spinning, and forging

   e. Joinable by shielded arc or electric resistance welding

   f. Low electrical resistivity and high thermal conductivity

   g. Nonmagnetic, nonsparking, and nontoxic alloys.

3.14 MAGNESIUM ALLOYS

Like aluminum, pure magnesium is too soft for structural members; it must be alloyed to acquire strength and structural usefulness. For specific applications, most varieties of magnesium alloys contain aluminum as the principal alloying agent. Zinc and manganese are also included to attain corrosion resistance. The most common magnesium alloys are as follows.

3.14.1 MAGNESIUM-MANGANESE

The binary alloys of magnesium and manganese, containing about 1.5 percent manganese, are used primarily for extrusions and, to a limited extent, for castings. These alloys are rated as being among the most corrosion resistant. Unfortunately, the manganese added has only a small hardening and strengthening effect. For this reason, castings of this composition are employed only for special applications. However, until the early 1950's, magnesium alloyed with 1.5 percent manganese was a prominent alloy used for sheets in both this country and abroad because of its higher resistance to corrosion than other known sheet alloys. One advantage of magnesium-manganese alloys is that they appear to be immune to stress-corrosion cracking under any condition so far encountered, either in accelerated stress-corrosion tests or in service.

3.14.2 MAGNESIUM-ALUMINUM-MANGANESE

Aluminum is the principal alloying element used to increase the mechanical properties of magnesium alloys. The principal magnesium-aluminum-manganese alloy is a casting alloy with the nominal content of 10 percent aluminum and 0.2 percent manganese. Of the currently used magnesium alloys, this alloy has the best casting characteristics for use in sand and permanent molds. Because the corrosion resistance of magnesium-aluminum-manganese alloys is inferior to that of the magnesium-aluminum-zinc-manganese alloys, the former is seldom specified for corrosion-resistant service.

3.14.3 MAGNESIUM-ALUMINUM-ZINC-MANGANESE

Most commercial magnesium alloys, both wrought and cast, contain aluminum, zinc, and manganese. Among other things, zinc, like manganese, serves to improve the alloy's resistance to corrosion. Additionally, 3 percent zinc in magnesium-aluminum-manganese alloys greatly increases the tolerance of the alloy to any included iron and nickel, and markedly reduces the undesirable effects of such inclusions when they are present in excess of the tolerance limit. Smaller quantities of zinc have a similar, though less pronounced, effect. A higher zinc content seems to result in somewhat higher resistance to corrosion; all of the zinc-containing alloys are more corrosion-resistant than the 10 percent aluminum alloy containing no zinc.

Table 3-6 lists those magnesium alloys in common use, their applications, and alloying agents. Table 3-7 lists the typical mechanical properties of magnesium alloys.

3.15 CORROSION OF MAGNESIUM

The corrosion resistance of magnesium is controlled largely by surface films; most of these films are quite resistant when exposed to strong alkalinity, but are rapidly attacked by mild acid concentrations. The thickness and nature of the film are largely determined by the manner in which the alloy is treated during processing. Magnesium and most of the magnesium-base alloys resist corrosion for long periods of time when unpainted and exposed to the atmosphere on test racks in various environments. However, the rate of attack on commercial magnesium when immersed in salt water is so high that its use under such conditions is not recommended even with the best protective paint system. Metallic pockets, where moisture contaminated with salt may collect, are extremely susceptible to corrosion, and the deterioration rate approaches that of immersion in salt water even though the structure may be some distance from the beach. Unavoidable contacts between magnesium alloy parts and the highly cathodic metals such as iron, copper, and nickel greatly complicate the successful use of magnesium in corrosive environments, especially in the presence of salt water or a saline-contaminated environment. Possibilities of contact between a magnesium alloy and any dissimilar metal should be studied carefully; such contact should be protected from galvanic action. Such a joint may be

electrically insulated or sealed from electrolytes, or another metal which creates less potential difference might be used.

Table 3-8 features the solution potentials of various magnesium alloys and emphasizes the vulnerable position of magnesium in any unprotected dissimilar metal couple.

The values listed in table 3-8 are applicable to many normal and saline-contaminated environments, but in strongly acidic or basic conditions, the relative order of the metals and alloys would not remain as listed. The greater the difference in potential between the magnesium and its alloying elements the greater the effect in lowering the resistance to corrosion. Potential differences between dissimilar metals indicate the direction of current flow and consequently indicate which element of the couple will suffer selective attack. The magnitude of the current involved depends on the difference in potential between the dissimilar metals, the polarization characteristics of the two metals, the nature and concentration of the solution they are subjected to, and the relative areas of the dissimilar metals exposed, and other factors.

3.16 SURFACE TREATMENTS FOR MAGNESIUM

Considerable progress has been made in the corrosion-control treatment of magnesium alloys. There are various anodizing, chrome, and dichromate treatments that provide various degrees of corrosion resistance when used in the appropriate environment. Several corrosion-retarding surface processes for magnesium follow.

3.16.1 CHROME PICKLE TREATMENT (DOW NO. 1)

A chrome pickle treatment (DOW No. 1) gives very little corrosion control if exposed. It is of the chemical immersion treatment type. The final color of the finish ranges from gray to reddish yellow. During treatment, there is a very slight removal of metal amounting to approximately 0.0006 inch for wrought magnesium. It is useful primarily in forming a coating to protect magnesium during shipment and storage; it also serves as a paint base. For details, refer to MIL-M-3171, type I.

Table 3-6. Magnesium Alloys in Common Use

| ASTM Alloy Designation | Temper [1] | Typical Composition in Percent | | | | Form |
		Al	Zn	Other	Magnesium	
AZ81A	T4	7.6	0.7			Sand and permanent mold casting
AZ92A	T6	9.0	2.0	—	Remainder	
AZ91A			0.6			Die castings
AZ31B		3.0	1.0			Extruded bars, rods, solids
AZ61A		6.5				
AZ80A	F	8.5	0.5			
M1A		—	—	1.2 Mn		
AZ31B		3.0	1.0	—		Extruded hollow shapes, tubing
AZ61A		6.5				
AZ31B	H10	3.0				Sheet and plate
AZ31B	H23					

Note

[1] Temper
   T4—Solution heat treated
   T6—Solution heat treated and artificially aged
   F—As fabricated
   H10—Slightly strain hardened
   H23—Strain hardened and partially annealed

Table 3-7. Properties of Magnesium Alloys

Alloy ASTM Designation	Temper[1]	Tension[2] Tensile Strength lbs/cu in.	Tensile Yield lbs/cu in.	Elongation in 2 inches, %	Compressive Yield Strength lbs/cu in.	Shear Strength lbs/cu in.	Hardness Brinell	Rockwell E
AZ81A	T4	40,000	14,000	12	14,000	17,000	55	66
AZ92A	T6		21,000	2	21,000		84	90
AZ91A	F	33,000	22,000	3	—	20,000	67	75
AZ31B[3]		38,000	29,000	15	14,000	19,000	49	57
AZ61A		45,000	33,000	16	19,000	20,000	60	72
AZ80A		49,000	36,000	11	—	22,000		77
M1A		37,000	26,000		12,000	18,000	44	45
AZ31B[4]		36,000	24,000	16			46	51
AZ61A		41,000		14	16,000		50	60
AZ31B	H-10	35,000	20,000	17	15,000	—	—	—
AZ31B	H-23	42,000	28,000	15	25,000		—	—

Notes

[1] Refer to note to table 3-6
[2] Typical test results
[3] Die castings
[4] Extruded hollow shapes, tubing

**Table 3-8. Solution* Potentials with Emphasis
on Magnesium**

Metal or Alloy	Potential (volts)
Magnesium	−1.73
Mg-4% Sn solid solution	−1.69
Mg-4% Al solid solution	−1.68
Zinc	−1.10
Mg_5Al_8	−1.07
$MgZn_2$	−1.04
Al-4% Zn solid solution	−1.02
Al-1% Zn solid solution	−0.96
Al-4% Mg solid solution	−0.87
$MnAl_6$	−0.85
Aluminum	−0.84
Al-1% Mg_2 Si solid solution	−0.83
Al-4% Cu solid solution	−0.69
$FeAl_3$	−0.56
Iron	−0.55
$CuAl_2$	−0.53
Silicon	−0.26
Copper	−0.20

* 53 grams NaCl + 3 grams H_2O_2 per liter N/10 calomel scale.

3.16.2 DICHROMATE TREATMENT (DOW NO. 7)

Dichromate treatment (DOW No. 7) gives very little corrosion control when exposed. Treatment type is chemical immersion. The final color ranges from dark brown through light brown to gray. No alteration in the thickness of the metal or other alteration of the metal results from this treatment; however, the precleaning and pickling may consume some metal. Its main use is as a paint base for most magnesium alloys. For details, refer to MIL-M-3171, type III.

3.16.3 GALVANIC ANODIZING (DOW NO. 9)

Galvanic anodizing treatment (DOW No. 9) gives very little corrosion control when exposed. Treatment type is electrochemical. The final color ranges from dark brown to black. No removal of metal results from the treatment; however, precleaning and pickling may dissolve some metal. Its main use is as a paint base on many magnesium alloys. For details, refer to MIL-M-3171, type IV.

3.16.4 HOT-ACID BATH ANODIZING (DOW NO. 17)

Hot-acid bath anodizing treatment (DOW No. 17*) gives fair corrosion control, especially if sealed. There are several types and classes of this treatment suitable for coating in thickness and function. The final colors range from light to dark green. Approximately one-third of the coat, which ranges from 0.0001 to 0.0027 inch, penetrates the metal. It is mainly useful in providing surface hardness and abrasion resistance in a paint base. For details, refer to MIL-M-45202.

3.16.5 CHROMATE TREATMENT (DOW NO. 19)

Chromate treatment (DOW No. 19) is a flexible corrosion-control process. The treatment can be applied by spray, brush, or dip, and thus is useful for field repair work. It is mandatory preparation for any field painting of magnesium alloys.

3.16.6 ANODIC TREATMENT (HAE)

Anodic treatment (HAE†) gives fair corrosion control. Treatment type is a permanganate-aluminate fluoride-cold process. Several types and many classes of this treatment are suitable for magnesium. The finished surface is tan color. The thickness ranges from 0.0001 to 0.0011 inch. There are many ways to seal HAE coatings. For details, refer to MIL-M-45202.

3.16.7 ELECTROPLATING

Magnesium is electroplated so that it will meet architectural requirements, possess a harder surface, and have better resistance to corrosion. Several metals can be electrodeposited on magnesium alloys. The nickel plating of magnesium alloy members which are to be installed adjacent to nickel, for example, gives excellent corrosion control. Metals that can be electrodeposited (such as copper, cadmium, zinc, brass, silver, and chromium) can be plated on properly prepared magnesium alloys. The procedure for electroplating magnesium is rigidly defined.

* A licensed process.
† A U.S. Government development.

PART D. NICKEL

Nickel is one of the most useful alloying elements known; it plays an important part in more than 3000 commercial and special metals. The popularity of nickel derives from its ability to impart so many desirable characteristics to the resulting alloy or metal combination. The most important characteristics are high resistance to corrosion, greater strength, ductility, and toughness. A prime use of nickel is as an alloying agent in stainless steels, corrosion-resistant alloys, cast iron, hardenable steels, nickel-silver, copper-nickel, and copper-aluminum-nickel.

3.17 CHARACTERISTICS OF NICKEL

a. Silvery white
b. Corrosion resistant in many environments
c. Ductile
d. Malleable
e. Adaptable to forging, casting, plating
f. Magnetic
g. Good thermal and electrical conductivity.

3.18 NICKEL ALLOYS

There are so many nickel alloys divided into and cross referenced by so many different categories that this presentation can include only a few members of the nickel alloy family. One method of nickel alloy classification is based on chemical composition as follows:

a. *Pure Nickel*

(1)	Electrolytic	99.80 percent Ni
(2)	Commercially pure, wrought (nickel 200)	99.0 percent Ni
(3)	Anode, rolled carbon	99.4 percent Ni & Co.
	Anode, cast carbon	99.33 percent Ni & Co.
	Anode, rolled depolarized	99.75 percent Ni & Co

b. *Nickel and Copper*

(1)	Low-nickel alloys	2 to 13 percent Ni
(2)	Copper nickels	10 to 40 percent Ni
(3)	Nonmagnetic	up to 60 percent Ni
(4)	High-nickel alloys	60 percent and higher Ni

(5) The most important nickel-copper alloy is Monel* alloy 400. Monel contains approximately 66 percent nickel and 33 percent copper. It has good resistance to salt water and has high strength. Other Monel alloys are as follows:

a. Monel alloy 506—cast alloy with 3 percent silicon for abrasion and corrosion resistance

b. Monel alloy K500—wrought alloy with age-hardenable feature

c. Monel alloy 501—wrought alloy with a higher-carbon content than K500 for improved machinability

d. Monel alloy R405—wrought alloy with 0.035 percent sulfur to improve machinability

e. Monel alloy 505—cast alloy with 4 percent silicon for abrasion and corrosion resistance.

c. *Nickel and Iron*

(1)	Wrought alloy steels	to 18 percent Ni
(2)	Cast alloy steels	to 18 percent Ni
(3)	Cast alloy iron	1 to 36 percent Ni
(4)	Magnetic alloys	20 to 90 percent Ni
(5)	Nonmagnetic alloys	10 to 20 percent Ni
(6)	Low expansion alloys	to 42 percent Ni

d. *Nickel and Aluminum—bearing alloys* — 1 percent Ni

e. *Nickel, Chromium, and Iron*

(1)	Electrical resistant alloys	to 60 percent Ni
(2)	Stainless steels	to 25 percent Ni

(3) Variations of the Ni, Cr, and Fe alloys contain as much as 78 percent nickel
(4) Inconel* alloy 600 with 77 percent Ni and 15 percent Cr has very good mechanical properties and high resistance to corrosion.

f. *Nickel, Copper, and Zinc*

(1) Nickel silvers, up to 30 percent Ni
(2) Also known as German silver but contains no silver
(3) Composition ranges from 52 to 80 percent copper, 5 to 30 percent nickel, and 5 to 35 percent zinc
(4) Silver white in color
(5) Increased strength and resistance to corrosion
(6) The *Copper Development Association Handbook* lists 25 specific types
(7) Copper alloy 752 underwent a 3,300 day immersion test in sea water at Harbor Island in North Carolina; the corrosion rate was less than 0.0005 inch per year. In the splash zone, the corrosion rate was even lower.

g. *Nickel and Silicon.* Hastelloy† alloy D contains 10 percent Si and can be cast; however, it is too hard to machine and must be ground. It has high strength, hardness, corrosion resistance.

h. Features of primary interest concerning nickel alloys are listed in table 3-9.

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* The name Inconel is a registered trademark of the International Nickel Company, Inc.

† The name Hastelloy is a registered trademark of the Union Carbide Corp.

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* Monel is a registered trademark of the International Nickel Company, Inc.

Table 3-9. Nickel Alloys

Alloy	Percentages of Principal Elements	Type	Strengths		Elongation in 2 inches, %	Brinell Hardness 3000 kg
			Tensile 1000 psi	Yield .2% offset 1000 psi		
Nickel	97 Ni—1.5 Si 0.5 Mn—0.5C	Cast	45 to 60	20 to 30	15 to 30	80 to 125
Nickel	99.4 Ni—.2 Mn .15 Fe	Wrought	50 to 165	10 to 155	2 to 65	90 to 230
Duranickel Alloy 301	93.7 Ni—4.4 Al .5 Si	Wrought	90 to 240	30 to 180	2 to 50	
Monel [1] Alloy 400	67 Ni—30 Cu 1.4 Fe—1.0 Mn	Wrought	70 to 170	25 to 160	2 to 50	110 to 250
Monel Alloy 411	67 Ni—29 Cu 1.5 Fe—1.2 Si	Cast	65 to 90	32 to 40	25 to 45	125 to 150
Constantan	43 Ni—55 Cu 1.0 Mn	Wrought	60 to 135	30 to 120	.5 to 45	
Copper Nickel Alloy 715	30 Ni—70 Cu	Wrought	40 to 80	20 to 70	3 to 55	
Nickel Silver Alloy 11A	20 Ni—65 Cu 6 Zn—5 Pb—4 Sn	Cast	42 to 48	23 to 28	12 to 16	90 to 100
Nickel Silver Alloy 752	18 Ni—64 Cu 18 Zn	Wrought	60 to 105	25 to 80	3 to 40	70 to 200
Nickel Chromium 80-20	78 Ni—20 Cr 2 Mn	Wrought	100 to 190	50 to 100	.5 to 35	150 to 320
Inconel [1] Alloy 610	71.0 Ni—15.5 Cr 9 Fe—2 Si—1 Cb	Cast	70 to 90	30 to 45	10 to 30	160 to 190
Inconel Alloy 600	77 Ni—15 Cr 7 Fe	Wrought	80 to 185	25 to 175	2 to 50	120 to 290
50-50 Nickel-Iron	50 Ni—49 Fe	Wrought	70 to 150	25 to 140	.5 to 35	30 to 60
Hastelloy [2] A	57 Ni—20 Fe 20 Mo—2 Mn	Cast Wrought	69 to 78 110 to 120	43 to 45 47 to 52	8 to 12 40 to 48	155 to 200 200 to 215
Hastelloy B	62 Ni—30 Mo 5 Fe	Cast Wrought	75 to 82 130 to 140	55 to 57 60 to 65	6 to 9 40 to 45	190 to 230 210 to 235
Hastelloy C	58 Ni—17 Mo 14 Cr—5 Fe	Cast Wrought	72 to 80 115 to 128	45 to 48 55 to 65	10 to 15 25 to 50	175 to 215 160 to 210
Hastelloy D	85 Ni—10 Si 3 Cu	Cast	36 to 41	36 to 41	0	

Notes
[1] Inconel and Monel are registered trademarks of the International Nickel Company Inc.
[2] Hastelloy is a registered trademark of Union Carbide Corp.

3.19 THE CORROSION OF NICKEL

The corrosion resistance of nickel alloys is well documented. The Harbor Island corrosion laboratory of the International Nickel Company, Inc., Wrightsville Beach, N. C., which includes marine atmosphere (harsh) test lots at Kure Beach, has been subjecting nickel alloys to a comprehensive and detailed series of corrosion tests for many years. The fact that nickel is used in so many alloys attests to its corrosion resistance. The cop-

per-nickel grouping illustrates some interesting aspects of the corrosion resistance of nickel alloys. Because nickel and copper are mutually soluble in any proportions, and since copper is more noble than nickel (as manifested by their positions in the electromotive series), it would seem that the higher the percentage of copper in the alloy, the more resistant to corrosion the alloy would be. However, nickel acquires passivity in some environments so that as the nickel content is increased, the resultant alloy becomes more corrosion resistant when used under conditions where passivity can be maintained. Plating is another use of nickel in preventing corrosion. The use of nickel for plating steel merely to prevent corrosion is a questionable practice since nickel is more noble than steel and thus protects the steel only by serving as a barrier. There is no cathodic protection for the steel if the nickel coating is ruptured; the steel adjacent to such a rupture will sacrifice itself to protect the nickel.

3.20 USE OF NICKEL FOR MSFN TRACKING STATION FACILITIES

The great range of thermal, electrical, strength, decorative, corrosion-resistant, and machinability properties of nickel alloys is worthy of much consideration for those MSFN tracking stations located in harsh environments. Nickel plating offers good barrier-type resistance for ferrous metals when properly applied. (For details, refer to QQ-N-290.) A considerable variety of nickel plating activity is available to cover a multitude of requirements. Table 3-10 includes qualitative ratings for the corrosion resistance of various nickel alloys in normal and harsh environments.

Table 3-10. Comparison of Corrosion Ratings with Emphasis on Nickel

Metal	AISI Type No.	Environmental Performance		MSFN Tracking Station Facility Usage
		Normal	Harsh	
Low-carbon steel	—	Poor	Very Poor	Must be protected by coatings
12—14% Chromium steel	420	Very Good	Fair	Check carefully for use in harsh environments
16—18% Chromium steel	430			
17% Cr, 7% Ni steel	301		Very Good	
18% Cr, 12% Ni 3% Mo steel	316	Excellent		Suitable for all MSFN tracking station environments
Monel alloy 400				
80% Ni—20% Cr	—		Excellent	
Inconel alloy 60 80% Ni—13% Cr—7% Fe				
Hastelloy alloy C				

PART E. STAINLESS STEEL

3.21 THE SELECTION OF STAINLESS STEEL

Engineers and architects are often confronted with the problem of when to consider stainless steels for a specific job. These corrosion-resistant metals should be considered if certain requirements exist:

a. High strength is required

b. Low permeability and nonmagnetic properities are desired

c. Long service life is a requisite

d. Appearance is important

e. Contamination of products is not permissible

f. Corrosion is a high-cost item in dollars or downtime

g. Special mechanical properties are demanded (for example, high creep strength at elevated temperatures).

The four qualifications which concern the MSFN tracking station facilities are corrosion control, longevity, high strength, and low permeability.

3.22 COMMON CHARACTERISTICS OF STAINLESS STEELS

All stainless steels:
- a. Contain a minimum of 11 percent chromium
- b. Contain iron and iron carbides
- c. Are alloys in solid solution *(annealed)*
- d. Can be active or passive
- e. Are divided by crystallographic structure.

The American Iron and Steel Institute lists 38 standard types of stainless steels; however, many of these are not suitable for MSFN tracking facility usage. In addition to these types, there are many nonstandard grades. Both the standard and most of the nonstandard grades can be grouped into three categories which are based on alloy content and crystallographic differences. The various groups and subgroupings of the stainless steel family provide quite an assortment of metals. The stainless steels are usually referred to as martensitic, ferritic, and austenitic; they are then further qualified.

3.23 MARTENSITIC, FERRITIC, AND AUSTENITIC STAINLESS STEELS

3.23.1 MARTENSITIC STAINLESS STEELS

Martensitic stainless steels have the following characteristics:
- a. Are in the AISI 400 series
- b. Contain 11.50 to 18.0 percent chromium
- c. Can be hardened by heat treatment
- d. Have a body-centered tetragonal crystal structure
- e. Can be machined satisfactorily (416 and 416 Se were developed specifically for machined parts)
- f. Are strongly magnetic
- g. Have a wide range of strengths; for example, AISI type 410 when annealed has:
  - (1) 32,000 psi yield
  - (2) 60,000 psi ultimate
  - (3) 200 max Brinell hardness.
  - AISI type 410 when heat treated has the following ~~results~~ *strengths:*
  - (1) 35,000 to 180,000 psi yield
  - (2) 60,000 to 200,000 psi ultimate
  - (3) 120—400 Brinell hardness.
- h. Are less resistant to corrosion than the ferritic and austenitic stainless steels; AISI type 410 or any 12-percent chromium

steel would show signs of surface corrosion within several months in a ~~hard~~ *saline* environment.
- i. The principal variations in the martensitic stainless steels are:
  - (1) 410—basic type, 12 percent chromium
  - (2) 403—12 percent Cr adjusted for physical properties
  - (3) 414—nickel added to increase corrosion resistance
  - (4) 416—sulfur or selenium added for easier machining
  - (5) 418—tungsten added to improve high temperature properties
  - (6) 420—high carbon for cutting ease
  - (7) 420 F—sulfur or selenium added for easier machining
  - (8) 431—higher chromium and nickel added for better wear resistance.

Tables 3-11 and 3-12 show the composition and properties of the alloys of interest to the MSFN facilities.

3.23.2 FERRITIC STAINLESS STEELS

The ferritic stainless steels:
- a. Are in the AISI 400 series
- b. Contain *12* to 27 percent chromium
- c. Cannot be hardened; may be drawn, formed, and welded; are more machinable than the austenitic grades
- d. Have a body-centered cubic crystal structure
- e. Are strongly magnetic
- f. Cannot be heat treated; however, the steel can be annealed with the following results:
  - (1) 35,000 psi yield
  - (2) 60,000 psi ultimate
  - (3) 200 max Brinell hardness
- g. Are more corrosion resistant than martensitic type
- h. Are subject to attack in a saline-contaminated atmosphere
- i. Principal variations in the ferritic stainless steels are:
  - (1) 430—basic type, 17 percent chromium
  - (2) 405—12 percent Cr + Al to prevent hardening
  - (3) 430 F—sulfur or selenium added to facilitate machining
  - (4) 442—high Cr to increase corrosion and oxidation resistance
  - (5) 446—much higher Cr to increase corrosion and oxidation resistance.

Tables 3-11 and 3-12 show the composition and properties of the alloys of interest to the MSFN facilities.

Table 3-11. Stainless Steel Compositions for General and Special Uses

AISI Type	Percentages					Corrosion Notes
	C	Mn Max	Si Max	Cr	Ni	
Martensitic (hardenable by heat treatment)						
403	0.15 Max	1.00	0.50	11.5—13.0	—	Good resistance to corrosion, reduced resistance in harsh environments because salt destroys passivity.
410		1.00	1.00	11.5—13.5		
414	0.15 Max	—		11.5—13.5	1.25—2.50	Corrosion resistance similar to types with straight 12% Cr but metal is tougher.
416		1.25				Usually a higher corrosion rate than other 12—14% Cr types.
416Se		1.25		12.0—14.0	—	
420			1.00			Good resistance to corrosion in general.
431	0.20 Max	1.00	1.00	15.0—17.0	1.25—2.50	High Cr gives good corrosion resistance.
440A	0.60—0.75					Good corrosion-resistant surface is obtained by polishing and dipping in a 15% HNO_3 solution followed by a good water wash.
440B	0.75—0.95			16.0—18.0	—	
440C	0.95—1.20					
Ferritic (nonhardenable)						
405	0.08 Max	1.00		11.5—14.5		Good corrosion resistance in all environments except harsh.
430		1.25				More corrosion resistant than type 405 but less corrosion resistant than the austenitic alloys.
430F	0.12 Max	1.25	1.00	14.0—18.0		
430Se		1.00			—	
442	0.25 Max	1.00		18.0—23.0		Good resistance to corrosion—between type 430 and 446.
446	0.20 Max	1.50		23.0—27.0		Very good resistance to atmospheric corrosion.

AISI Type	Percentages					Corrosion Notes
	C	Mn Max	Si Max	Cr	Ni	
Austenitic (hardenable by cold work)						
201	0.15 Max	7.50	1.00	16.0—18.0	3.5—5.5	Types 201 and 202 are quite similar to 301 and 302 but with lower Ni and higher Mn.
202		10.00		17.0—19.0	4.0—6.0	
301				16.0—18.0	6.0—8.0	Types 301, 302, 302B, 304, 305, and 308 are resistant to a wide range of corrosive media. They have good resistance to oxidation up to 1500°F; they are susceptible to intergranular corrosion if improperly heated and cooled. Type 302B is less resistant to wet corrosive conditions than type 302.
302		2.00		17.0—19.0	8.0—10.0	
302B			2.0—3.0			
304	0.08 Max			18.0—20.0	8.0—12.0	
304L	0.03 Max					
305	0.12 Max			17.0—19.0	10.0—13.0	
308	0.08 Max		1.00	19.0—21.0	10.0—12.0	
303	0.15 Max			17.0—19.0	8.0—10.0	Not as resistant to corrosion in general as the 300 types listed immediately above, form rust film in moist environments and are susceptible to localized and pitting attack in the presence of chlorides.
303Se						
309	0.20 Max			22.0—24.0	12.0—15.0	High resistance to corrosion at elevated temperatures below 2000°F; if temperature cycles, 309 will shed scale due to expan/contrac.
309S						
310	0.25 Max		1.50	24.0—26.0	19.0—22.0	Good resistance to corrosion and oxidation at elevated temperatures below 2100°F.
310S						
314		—	1.5—3.0	23.0—26.0		Never used for resistance to wet corrosion, more suited to elevated temperature use.
316	0.08 Max			16.0—18.0	10.0—14.0	Types 316 & 317 are more resistant to atmospheric and similar mild types of corrosion than the regular unmodified Cr-Ni stainless steels. The 2.0—3.0% molybdenum makes these types less susceptible to pitting or pin hole corrosion in the presence of chlorides.
316L		—	—			
317	0.10 Max			18.0—20.0	11.0—14.0	
321	0.08 Max			17.0—19.0	9.0—12.0	Resistant to intergranular corrosion, type 321 will develop a light rust film when exposed to harsh environments.
347					9.0—13.0	

Table 3-12. Properties of Annealed Stainless Steels

AISI Type	Yield Strength lbs/sq in.	Tensile Strength lbs/sq in.	Machining and Fabricating Guide Notes	General Guide Notes
Martensitic ~~(hardening)~~ *(hardenable by heat treatment)*				
403	45,000	70,000	Machinability 55—60% [3]	For production of highly stressed parts.
410 [1]			Drawing characteristics similar to low "C" unalloyed steel	Light rust film after several weeks exposure and, except in harsh environments, film acts as barrier to further corrosion.
414	105,000	120,000	Higher mechanical properties than 410	Increased corrosion resistance over type 410.
416	40,000	75,000	Machinability 65—80% [3]	Most readily machinable of all ~~stainless steels~~ *the Martensitics*, inferior to 430F in corrosion resistance.
416Se			Free machining version of type 416	Corrosion resistance lower than 416.
420	50,000	95,000	Machinability 65—75% [3]	Maximum corrosion resistance only in fully hardened condition (500 Brinell).
431	95,000	125,000	Machinability 40—50% [3]	Higher corrosion resistance than 410, 420, 430 & 440. 431 is magnetic in all conditions.
440A	60,000	100,000		Magnetic in all conditions, reduced corrosion resistance, tougher than 440B or 440C.
440B	62,000	107,000		Reduced corrosion resistance.
440C	65,000	110,000	High carbon causes abrasion to cutting tool edges.	Can achieve highest hardness of any corrosion resistant steel, excess carbon in microstructure reduces corrosion resistance.
Ferritic (nonhardening)				
405	40,000	65,000	Al added to prevent hardening	Can be bent cold, magnetic in all conditions.
430 [1]	50,000	75,000	Machinability 50—55% [3]	Do not use nonnickel-bearing solder with 430; the interface is very corrosion prone.
430F	55,000	80,000	Machines 90% as freely as mild steel	Most readily machinable of the entire stainless steel family.
430Se			Suitable for automatic screw machines	The 430F and 430Se are magnetic in all conditions.
442	45,000		Machinability 40—50% [3]	Increased scaling resistance in heat, magnetic in all conditions.
446	50,000			Very high scaling resistance in heat, magnetic in all conditions.

Table 3-12. Properties of Annealed Stainless Steels (cont.)

AISI Type	Yield Strength lbs/sq in.	Tensile Strength lbs/sq in.	Machining and Fabricating Guide Notes	General Guide Notes
Austenitic (hardenable by cold work)				
201	55,000	115,000	Usually for flat products	Mechanical properties higher than in the annealed condition are obtained by cold rolling or cold drawing.
202		105,000	Good forming characteristics	201 and 202 developed to conserve nickel.
301 [4]	40,000	110,000	Good ductility	Use only in comparatively mild corrosive areas.
302 [1],[4]		90,000	Best all around Cr/Ni drawing grade	
302B [4]		95,000	Machinability 30—40% [3]	Never use in wet corrosive areas, good oxidation resistance at high temperature.
303	35,000	90,000	Most readily machinable of austenitic grades	Type 300 grades exhibit maximum corrosion resistance when Cr, Ni, C, and Fe are in solid solution.
303Se			Free machining version of type 303	Anneal after welding to avoid intergranular corrosion.
304 [4]	42,000	84,000	Machinability 30—40% [3]	Higher corrosion resistance than type 302, lower carbon to avoid carbide precipitation.
304L	39,000	81,000	Use for parts which must be welded	Low carbon content affords better protection against intergranular corrosion than 304.
305 [4]	38,000	85,000	Good in special drawing and cold heading.	Higher nickel for less work hardening.
308 [4]	35,000		Slightly magnetic when cold worked	Better corrosion resistance than any other type of the family marked with footnote [4].
309	45,000	90,000	Machinability 30—40% [3]	For fire box sheets, pump parts, and hot worn zones, resists oxidation temperature up to 2000°F.
309S		95,000	Not good for cold heading	Slightly less chance of intergranular corrosion because of less carbon.
310				High chromium and nickel content to improve scaling resistance in heat.
310S			Nonmagnetic when annealed or cold worked	High heat-resisting properties.
314	50,000	100,000		Highest heat-resisting properties of the austenitics.

Table 3-12.   Properties of Annealed Stainless Steels (cont.)

AISI Type	Yield Strength lbs/sq in.	Tensile Strength lbs/sq in.	Machining and Fabricating Guide Notes	General Guide Notes
Austenitic (cont.)				
316	42,000	84,000	Machinability 30—40% [3]	A good choice for coastal installations.
316L		81,000		Lower carbon content affords better protection against intergranular corrosion.
317	40,000	90,000		A good choice for coastal installations.
321 [2]	35,000		Machinability 35—45% [3]	Since titanium oxidizes rapidly in heat, type 321 must be welded with type 347 rods.
347 [2]	40,000	95,000		Immune to intergranular corrosion.
Notes				

[1] Basic type of each group.
[2] Stabilized grades are made immune to transgranular corrosion by proper additions of columbium & tantalum.
[3] Machinability rate for Bessemer screw stock is 100%.
[4] Improper heating or cooling in the 800-1500°F range may eventually result in intergranular corrosion.

3.23.3 AUSTENITIC STAINLESS STEELS

The austenitic stainless steels have these characteristics:

a. Are in two AISI groups: the 200 series and the 300 series. The 200 series is essentially Cr, Ni, and Mn; the 300 series is essentially Cr and Ni.

b. Contain 16 to 26 percent chromium and 3.5 to 22 percent nickel

c. Contain a maximum of 0.15 percent carbon

d. Can be hardened by cold working, not by heat treatment

e. Have a face-centered cubic crystal structure

f. Are nonmagnetic in the annealed condition; cold working will develop magnetic properties.

g. Have a wide range of strengths; for example, AISI type 302 when annealed results in:
   (1) 30,000 psi yield
   (2) 80,000 psi ultimate
   (3) 180 max Brinell hardness
   Strength is increased by cold rolling or drawing.

h. May be subject to intergranular corrosion if heated to such an extent (800°F—1500°F) that carbide precipitation occurs.

i. The high chromium-nickel low manganese stainless steels appear to be more corrosion resistant in saline-contaminated atmosphere than other types.

j. Principal variations in the austenitic stainless steels are:
   (1) 302—basic type, 18 percent Cr, 8 percent Ni
   (2) 301—Cr and Ni lower to permit more work hardening
   (3) 304—lower C to avoid carbide precipitation
   (4) 305—higher Ni for less work hardening
   (5) 303—sulfur or selenium added to aid machining
   (6) 316—molybdenum added for corrosion resistance
   (7) 317—higher Mo content for higher corrosion resistance and strength at heat
   (8) 321—titanium added to avoid carbide precipitation
   (9) 308—higher Cr and Ni with lower C for more corrosion and scaling resistance

Tables 3-11 and 3-12 show the composition and properties of the alloys of interest to the MSFN facilities.

3.24 CORROSION CONTROL ON STAINLESS STEEL

Stainless steels are corrosion resistant but they are not corrosion proof. Understanding the limitations of the various alloys of stainless steel in regard to corrosion allows the designer and the engineer to fully use the great potentials of these metals.

3.24.1 ATMOSPHERIC CORROSION

The corrosion resistance of the stainless steels is primarily a function of the chloride content of the environment; the proximity of the ocean or other sources of chloride contamination is significant. Other factors which are important in determining the atmospheric-corrosion performance of other metals (sulfur contamination, for example) are not particularly significant with the stainless steels. The amount of rainfall is important only as it affects the concentration of chlorides at the steel surface. In harsh environments, certain stainless steels will develop a thin rust film in a short period of time, but there will be no appreciable dimensional change (types 410 and 430). Certain austenitic stainless steels may develop some rust staining when exposed in marine environments (types 301, 302, or 304). The staining is usually superficial and can be easily removed. Stainless steel, which contains molybdenum, is essentially resistant to rust staining in marine environments (type 316). The performance of austenitic stainless steels exposed to a marine atmosphere 800 feet from the ocean at Kure Beach, North Carolina, for a period of 15 years is shown in table 3-13. The rust stain that developed on the stainless steels was easily removed, even after 15 years, and the surfaces of the materials were found to be bright.

3.24.2 PITTING CORROSION

The excellent corrosion resistance of stainless steels results from the formation of an invisible oxide film that covers the steel surface. This oxide film halts further oxidation; it makes the surface passive. The passive film may form either as a result of the steel reacting with oxygen in the atmosphere or from contact with other oxygen-containing environments. If the passive film is destroyed, corrosion may develop where the film is broken. When the passive film is destroyed in small localized areas on the metal surface, corrosion will occur in the form of very small pits (localized corrosion). The affected area or pit becomes anodic to the surrounding passive surface and once an electrode is provided, the oxidizing action of electrochemical corrosion begins. The subsequent development of these active anodic areas into deep pits is a direct result of the flow of current between the small anodic area and the

Table 3-13. Performance of Stainless Steels in a Harsh Environment*

AISI Type	Average Corrosion Rate, mpy	Average Depth of Pits, mils	Appearance [1]
301	0.001	1.6	Light rust and rust stain on 20 % of surface
302	0.001	1.2	Spotted with rust stain on 10 % of surface
304	0.001	1.1	Spotted with slight rust stain on 15 % of surface
321	0.001	2.6	Spotted with slight rust stain on 15 % of surface
347	0.001	3.4	Spotted with moderate rust stain on 20 % of surface
316	0.001	1.0	Extremely slight rust stain on 10 % of surface
317	0.001	1.1	Extremely slight rust stain on 20 % of surface
308	0.001	1.6	Spotted by rust stain on 25 % of surface
309	0.001	1.1	Spotted by slight rust stain on 25 % of surface
310	0.001	0.4	Spotted by slight rust stain on 20 % of surface

Note

[1] All stains easily removed to reveal bright surface.

* Source—the International Nickel Company, Inc. Refer to table 2-4 for the definition of harsh environment.

large cathodic area. In many cases, particularly in chloride environments, the pits show undercutting. The *Corrosion Handbook* edited by H. H. Uhlig* describes the formation of pits and their prevention.

3.24.2.1 CONDITIONS THAT PROMOTE PITTING. Pitting is most likely to occur in the presence of chloride ions combined with such depolarizers as oxidizing salts. An oxidizing environment is usually necessary for preservation of passivity with accompanying high corrosion resistance, but, unfortunately, it is also a condition for occurrence of pitting. The oxidizer can often act as a depolarizer for passive-active cells established by a breakdown of passivity at a specific point or area. The chloride ion, in particular, can accomplish this breakdown.

Aerated neutral or nearly neutral chlorides can pit stainless steels. Pitting is less pronounced in rapidly moving aerated solutions than in partially aerated stagnant solutions because the flow of liquid carries away corrosion products which

would otherwise accumulate at crevices or cracks. It also ensures uniform passivity through free access of dissolved oxygen.

The pitting rate increases with the temperature. For example, in 4 to 10 percent sodium chloride solutions, a maximum weight loss produced by pitting is reached at 90°C (195°F); for more dilute solutions, this maximum occurs at still higher temperatures.

3.24.2.2 SEVERAL WAYS TO PREVENT PITTING. Several ways to prevent pitting are listed below.
a. Avoid concentration of halogen ions.
b. Ensure uniform oxygen or oxidizing solutions, agitate solutions, and avoid pockets of stagnant liquid.
c. Either increase oxygen concentration or eliminate it. Increasing oxidizing capacity of the solution augments passivity and resistance to attack. On the other hand, elimination of oxygen avoids passive-active cells as, for example, in salt solutions.
d. Increase the pH. As compared with neutral or acid chlorides, appreciably alkaline chloride solutions cause fewer pits or none

* The *Corrosion Handbook* is published by John Wiley and Sons.

at all. (The hydroxyl ion acts as an inhibitor.)

e. Operate at the lowest temperature possible.

f. Add passivators to the corrosive medium. A small concentration of nitrate or chromate is effective in many media. The inhibiting ions preferentially adsorb on the metal surface, thereby preventing adsorption and subsequent attack by the chloride ion. (See QQ-P-35 entitled *Passivation Treatments for Stainless Steels.*)

g. Apply cathodic protection. There is evidence that stainless steels protected cathodically by galvanic coupling to mild steel, aluminum, or zinc do not pit in sea water. (Note that it is not necessary to polarize the stainless steel to a potential more active than its open circuit value. It suffices to polarize [using sacrificial anodes or small impressed currents] only to a potential more active than the critical potential.)

h. The austenitic grades of the stainless steels containing 2 to 4 percent molybdenum exhibit the best resistance to pitting attack. Examples of specific corrosive media in which the use of molybdenum-containing austenitic stainless steels markedly reduces pitting attack or general corrosion are sodium chloride solutions, sea water, sulfurous acid, sulfuric acid, phosphoric acid, and formic acid.

3.24.3 INTERGRANULAR CORROSION

The grades of austenitic stainless steel that do not contain titanium or columbium and do contain more than 0.03 percent carbon are subject to intergranular corrosion in certain environments if improperly heat treated. These grades are known as unstabilized grades. The damage occurs when these steels are heated in the range of 800 to 1500°F or are slowly cooled through this range. Such heat treatments result in the precipitation of chromium carbides at grain boundaries (sensitization) and a depletion of chromium in immediately adjacent areas. This migration of chromium makes the low chromium areas susceptible to corrosive attack. Sensitization can occur during welding, causing subsequent localized corrosion in the heat-affected zone of the weld. The most commonly used method of checking for sensitization is the Huey test.* Intergranular corrosion of welded structures of austenitic stainless steel can be controlled as follows:

a. Use the low-carbon grades (types 304L or 316L) or the stabilized grades (types 321

* For details, refer to ASTM-A262-64T.

or 347). Use of these grades prevents a damaging amount of chromium carbide from precipitating during welding.

b. If the finished part is small enough to furnace anneal after fabrication, the part may be annealed at 1900 to 2100°F to dissolve the chromium carbides and rapidly cooled through the 800 to 1500°F range to prevent reprecipitation. It should be understood that the mere presence of intergranular carbides in austenitic stainless steel does not mean that intergranular corrosion will always occur. This phenomenon occurs only in specific corrosive environments. Addition of titanium to type 430 stainless steel in amounts greater than eight times the carbon content greatly reduces the intergranular attack of the welded steel in some media.

3.24.4 STRESS-CORROSION CRACKING

Stress-corrosion cracking is the combined action of static stress and corrosion; it leads to cracking or embrittlement of a metal. Only tensile stress causes this type of failure. *Practically all metals and alloys (with the exception of very pure metals) are subject to corrosion cracking in certain environments.* Hardened . (quenched and tempered) martensitic stainless steels are susceptible to stress-corrosion cracking in environments containing chlorides, hot caustics, nitrates, or hydrogen sulfide. For austenitic stainless steels, concentrated chloride and caustic solutions are the major agents causing stress-corrosion cracking. It should be noted that in many of these environments, the cracking may have been caused by the presence of impurities (chlorides, for example). The circumstances under which stress-corrosion cracking failures occur are usually complex. For example, the stress involved is normally not operating stress alone, but a combination of operational and residual stresses in the metal as the result of fabrication, welding, or heat treatment. Also as indicated, the corrosive agent that causes the cracking may be only an impurity in the product being handled. The amount of the corrosive agent present may not be great enough to cause cracking in the bulk solution, but a localized concentration of the agent in crevices or in the splash zone above the liquid may cause failure. The best preventive measure is to use a material that is resistant to stress-corrosion cracking in the environment in question as shown in table 3-14.

Table 3-13 lists the performances of various stainless steels in a harsh environment. The specimens were exposed for 15 years 800 feet from the ocean

Table 3-14. Stress-corrosion Cracking Resistant Materials

Environment	Resistant Material
Harsh	Ferritic stainless steels
Industrial (H$_2$S problems)	Ferritic and martensitic stainless steels

at Kure Beach, North Carolina. Table 3-15 is a qualitative rating given various materials to permit a comparison of corrosion resistance of stainless steels with other structural metals in similar environments.

Note

Stainless steel was used as a convenient platform for the discussion of intergranular corrosion and stress-corrosion cracking. These types of corrosion apply to many other metals and alloys.

3.25 STAINLESS STEEL FOR MSFN TRACKING STATION FACILITIES

It is reasonably safe to state that no other metallic alloy could do more to bring corrosion at the MSFN tracking facilities under excellent control than the correct stainless steels. The proper stainless steels for nuts, bolts, washers, cableways, brackets, electric connectors, concealed structural members, and gusset plates in humid and harsh environments may be excellent choices for both corrosion control and lifetime economics. Stainless steel fabrication of inaccessible structural members is not only a corrosion control measure, but also minimizes lifetime costs. These highly corrosion-resistant alloys can be painted or surface treated to match other components. The design phase is the opportune time to determine the most advantageous uses of stainless for the MSFN antennas; however, these high-alloy steels also offer advantages as repair or replacement metals such as nuts, bolts, washers, and shims.

Table 3-15. Comparison of Corrosion Resistance

Material	Atmosphere		Sea Water	1—20% Solutions of Alkalies	Salt solution (moderate concentrations)	
	Seashore	Industrial			NH$_4$Cl	MgSO$_4$
Ingot iron or wrought iron Low-carbon steel	p	p	f	g	p	fg
Low-alloy, high-strength structural steel	f	f		e		
Galvanized steel	g	g	fg	p		
Gray cast iron	f		f	g		
3½% Nickel cast iron	fg	fg	fg	ge		
17% Chromium-iron	g		pg	g	fg	
18% Cr—8% Ni stainless steel		g	fg			
25% Cr—20% Ni stainless steel			g		g	g
Nickel (99.2%) Inconel (80% Ni, 14% Cr, 6% Fe)	e		fe	e		
Hastelloy C (58% Ni, 17% Mo, 14% Cr, 5%W, 6% Fe)			e		e	e
Aluminum (99.2%)	ge		g	p	f	g
2024-T6 Aluminum alloy (4.5% Cu, 1.5 Mg, 0.6% Mn)	pg	fg	p			
Magnesium				e	p	p
Wrought magnesium alloys	g	g	f			
Tin			g	f		
Lead (99.9%)				p	fg	g

Note

e = excellent,   g = good,   f = fair,   p = poor

CHAPTER IV. PROTECTIVE COATING SYSTEMS

INTRODUCTION

4.1 GENERAL

Formulating a paint system for a complex structure demands detailed analysis and compromise. The structure, its environment, and the possible combinations of high-performance paints must first be totally examined. Obtaining this data involves chemistry, physics, metallurgy, and corrosion-control principles. These findings must then be considered. For example, the chemical and abrasion resistance of epoxy must be viewed against its tendency to chalk. Urethanes and alkyds give high performance, but urethane may yellow; alkyds smudge mark easily. A paint system to fulfill each and every requirement imposed by an MSFN antenna does not exist. All paint systems, therefore, can only be the best compromise of all the variables.

4.2 TECHNICAL

Painting has two ironclad rules. The first is to prepare the surface properly. High-performance paints are extremely critical of the surface to which they are applied. These paints will not adhere to rust, moisture, dust, salts, hydrocarbons, cold surfaces, hot surfaces, or chemical films. The second rule is to use compatible paints. Lifting, crinkling, and dissolving are results of incompatible paints. An inferior paint system is the only alternative to these rules. A corollary to the two rules is the requirement of good craftsmanship. Improper mixing, spraying, or drying can result in a paint system with a life of months or even weeks.

PART A. POSSIBILITY OF FLAWS IN STRUCTURAL METALS

The high-quality, high-cost surface preparation called whiteblast (SSP-SP5-63)* is considered by many to be the ultimate preparation for a ferrous surface. Whiteblast is often specified in contracts, but the achievement of a true whiteblast surface may not guarantee a high-quality substrate. Events that precede the sandblasting help to determine whether the whiteblast will perform as desired. The preceding events occur during the purification processing of the metals. It is erroneous, for example, to presume that all structural metal cut or rolled from a billet is completely homogeneous and uniform in structure. Even though today's commercial metals are almost invariably good metals having specified mechanical and metallurgical properties, quality variations do occur. Because the MSFN antenna structures are complicated and corrosion is difficult to control, the quality of the structural metal for an antenna should be as high as can be economically obtained.

There is some controversy regarding how much, if any, items such as sulfide inclusions or metal slivers in the surface of the metal affect the pro-

tective coating systems and corrosion rates. Some responsible investigators believe there is no noteworthy effect; other responsible investigators believe there is an impact and present the following data in support of their position:

a. An analysis of sulfur in the heat test of steel may be 0.06 percent, but that 0.06 percent may not be uniformly distributed; in a sulfide inclusion, the sulfur may approach 15 percent. When a billet is heated in a soaking pit having a 0.02-percent sulfur dioxide atmosphere, the metal may absorb sulfur which may penetrate the surface to a depth of 15 mils. Heating may change the location of sulfur. Sulfur may migrate to grain boundaries in welding operations. Subsurface oxidation may take place in sulfide inclusions. The sulfur may draw oxygen to the inclusion and act as a catalyst in oxidizing the surrounding Fe.

b. Working hot billets often produces Fe slivers which are truly slivers mechanically, not metallurgically, buried in the surface of the metal. Proper pickling may not remove all such slivers. These slivers

Steel Structures Painting Manual.

may be surrounded by enough oxygen to promote corrosion even though the metal is whiteblasted and covered with a good paint system. Close inspection of whiteblast surfaces may reveal only large slivers.

Such problems concerning flaws in structural metals, even though they be quite rare and of no concern to most users, should be given some thought when the steel is specified for a new antenna. Specifying steel with a 0.01-percent maximum sulfur content would be an expensive means of improving the condition; the use of maraging steel would also help and, of course, high caliber 100-percent quality control would be a good guarantee for high-quality metal. Finally, the sample testing of the structural steels can be considered. The Galvanizing Institute outlines a test procedure which may be significant. This simple test allows a statistical computation of the number of small slivers in a shipment of structural steel. Approximately a dozen pieces of the metal, each with a minimum area of 100 square inches, should be selected at random. (Ends of structural members are suitable because the test is not destructive.) The test areas are whiteblasted and hot dipped in a galvanizing bath. It is reported that surface slivers as small as 1/100 of an inch should rise as pimples within 3 minutes.

It should be remembered that there are no perfect structural materials. The degree of imperfection that should be permitted for the MSFN tracking station antennas has many economic, maintenance, and operational facets, and corrosion control has an impact in each of them.

PART B. SURFACE PREPARATION OF FERROUS METAL

The term "paint system" is interpreted so many ways that those other than full-time dedicated paint technicians or engineers often encounter definition problems. This study defines a paint system as the complete sequence of events that will provide a protective coating for a designated structure or equipment in a particular environment. It is a sequence which includes the proper surface preparation, the proper paint, and the proper application. The quality of the paint system depends primarily upon proper surface preparation; the quality of the paint and the paint application technique can be meaningful only on properly prepared substrates because new paint will hide most improperly prepared surfaces for a short time. Any compromising or economizing that is allowed in the painting system usually happens in the surface preparation phase. Such compromising is illogical because it can multiply repair costs.

4.3 PRINCIPLES OF SURFACE PREPARATION

There are specifications on the various classes of surface preparation in Air Force Civil Engineering Manuals, Army Corps of Engineers Manuals, Naval Facility Manuals, and Steel Structures Painting Council Manuals. These specifications are all similar and considered adequate for steel structures such as bridges, building frames, etc. However, because of the high-dollar value and complicated structures of the MSFN antennas plus the difficulty of scheduling downtime for painting, this study selected higher classes of surface preparation for the MSFN antennas than the Military and SSPC specifications would require. The higher classes of surface preparation are needed not only for greater operational periods between major repair paintings but also for sound economic reasons. Many principles should be given consideration when selecting the class of surface preparation for a particular paint system.

4.3.1 DIVISION OF FUNDS

    a. Surface preparation (Labor, material, equipment)   50—65 percent*

    b. Application (Labor and equipment)   20—30 percent

    c. Paint (Material)   5—15 percent

This allocation of funds is supported by pure logic because the very best paint is degraded by poor surface preparation. Any ferrous metal surface improperly prepared will corrode at a rate determined by its environment. Several MSFN tracking stations are in very harsh environments where a good paint system requires the very best surface preparation. To obtain maximum life of the paint system, proper surface preparation is mandatory.

4.3.2 CONSIDERATIONS IN SURFACE PREPARATION

    a. Environment

    b. Condition of surface to be painted

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* Inadequate surface preparation will result in premature failure at the paint/metal interface because of poor bonding.

c. Availability of structure or equipment
d. Accessibility to all parts of the structure or equipment
e. Surface preparation equipment and painting equipment
f. Safety factors
g. Type of paint
h. Economics.

4.3.3 SURFACE CONTAMINANTS

a. Dirt: mud, sand, soot, dust
b. Grease: fats, oils, and solid lubricants
c. Rust: Fe_2O_3, ferric oxide
d. Rust scale: all stages
e. Mill scale: loose and tight. (Refer to paragraph 2.5.9.)
f. Old coatings: paints, varnishes, primers, etc., in poor condition
g. Moisture, salts, acids, alkalis.

4.3.4 SURFACE DEFECTS

a. Weld flux
b. Weld splatter
c. Sharp edges
d. Metal burrs
e. Crevices
f. Bimetals
g. Flexing sections.

4.4 CLASSES OF SURFACE PREPARATION

4.4.1 CLASS I SURFACE PREPARATION FOR THE MSFN TRACKING FACILITIES

a. Used for short-lived and/or inexpensive structures in dry and normal environments. *It is not adequate for the original or major repair painting of antennas.*
b. Provides nominal cleaning with the least cost for limited areas; cleaning large areas with hand tools may be quite expensive.
c. Consists of hand-tool cleaning: chiseling, chipping, scraping, brushing (SSPC-SP2-63).
d. Uses power tools for removing small amounts of tightly adhering contaminants (SSPC-SP3-63).

CAUTION

Impact and power tools quickly cut deep; wire brushes can polish metal surfaces and prevent adequate bonding of paint.*

* Paint bond to metal is a mechanical bond with the paint binder drying on the metal surface. When the metal surface is very smooth, the degree of bond will be much less than if the metal is frosted by light sandblast or is roughened by acid etching.

e. Hand and power-tool cleaning should be preceded by solvent cleaning (SSP-SP1-63).
f. Brushoff sandblasting (SSPC-SP7-63) uses air-propelled abrasive materials to remove only the loosely adhering contaminants. It is a low-cost cleaning which supplements hand tools and achieves a uniform Class I surface preparation. It is much more economical for large areas than hand-tool cleaning. The brushoff sandblast cleaning rate using 100 pounds of air pressure per square inch with a 5/16-inch nozzle is approximately 800 square feet per hour. Masks and goggles are required for operators.
g. Types of paint to use are as follows:
   (1) Primers which will thoroughly wet the substrate (long oil and/or long-oil modified primers)
   (2) Primer which is of a type that will adhere satisfactorily to residue or which is capable of overpowering the interference of contaminants that will remain after Class I surface preparation.
h. Estimated paint life on Class I surface preparation for MSFN facilities is as follows:
   (1) In dry environment—1 to 5 years
   (2) In normal environment—1 to 3 years
   (3) In humid environment—3 to 8 months
   (4) In harsh environment—1 to 4 months.

4.4.2 CLASS II SURFACE PREPARATION FOR THE MSFN TRACKING FACILITIES

a. Provides a more thorough surface cleaning than Class I and is approximately twice as expensive. Class II surface preparation is the class advised for spot repair work undertaken by the station personnel. *It is not adequate for the original or major repair painting of antennas.*
b. Consists of the combination of flame cleaning and brushoff sandblasting. Flame cleaning (SSPC-SP4-63) is passing high velocity oxyacetylene over a metal surface; adequate ventilation is required; and there is a fire hazard with solvent-thinned paints. Standby fire extinguisher, breather mask, and goggles are required.
c. Oil and grease must be removed prior to flame cleaning (SSPC-SP1-63).
d. Subsequent to flame cleaning, the surface must be further cleaned by wire brush or brushoff sandblasting.

e. As an alternative to flame cleaning and brushoff sandblasting, use commercial blast.

f. Commercial blast (SSPC-SP6-63) uses air-propelled abrasive material for cleaning. All rust, mill scale, and old paints are removed except for light shadows, streaks, and discoloration caused by stains, mill scale, oxide, or slight residue of paint or coatings that might remain. The commercial sandblast cleaning rate using 100 pounds per square inch with a 5/16-inch nozzle is approximately 350 square feet per hour.

g. Estimated paint life on Class II surface preparation for MSFN facilities is as follows:

(1) In dry environment—3 to 6 years

(2) In normal environment—2 to 4 years

(3) In humid environment—6 months to 2 years

(4) In harsh environment—6 to 15 months.

4.4.3 CLASS III SURFACE PREPARATION FOR THE MSFN ANTENNAS

a. Requires a high degree of cleaning; sandblasting is the only feasible technique.

b. Consists of a near white metal blast (SSPC-SP10-63) and is *for use on antennas in dry, normal, and humid environments*. It uses air-propelled abrasive material for cleaning. The cleaned surface must be free from all oil, grease, dirt, mill scale, rust, corrosion products, oxides, paint, and other foreign matters. At least 95 percent of the surface will have the appearance of a surface blasted clean to a white metal finish. The remainder will be limited to very light streaks or slight discolorations caused by rust stain, mill scale, oxides, or slight, tight residues of paint.

c. Is less expensive (10 to 35 percent) than white metal blasting. The near white-blast cleaning rate using 100 pounds of air per square inch with 5/16-inch nozzle is approximately 160 square feet per hour. Breather mask and face shield are required for the operator.

d. Estimated coating life on Class III surface preparation for MSFN antennas is as follows:

(1) In dry environment—4 to 7 years

(2) In normal environment—2 to 6 years

(3) In humid environment—2 to 3 years

(4) In harsh environment—1 to 2 years.

4.4.4 CLASS IV SURFACE PREPARATION FOR THE MSFN ANTENNAS

a. Consists of a white metal blast (SSPC-SP5-63), the cleanest metal surface possible by sandblast; it can be used for any environment and is *mandatory for antennas in a harsh environment*. It provides for the complete removal of all contaminants leaving a uniform white or grayish surface. The term "white metal" is defined as a surface with a gray-white uniform metallic color, slightly roughened to provide a suitable anchor pattern for paint coatings. Sandblasting is the only feasible technique.

b. Is the highest cost surface preparation, but attains maximum performance and/or longevity. Because it can be six times as expensive as Class I cleaning, this level of surface preparation merits only the best paints and application techniques.

c. The safety minimum requires a mask and face shield.

d. The whiteblast cleaning rate using 100 pounds of air per square inch with a 5/16-inch nozzle is approximately 100 square feet per hour.

e. All dust must be completely removed before painting.

f. Estimated coating life of Class IV surface preparation for the MSFN antennas is as follows:

(1) In dry environment—5 to 10 years

(2) In normal environment—4 to 7 years

(3) In humid environment—1½ to 4 years

(4) In harsh environment—1 to 3 years.

4.5 SANDBLASTING

4.5.1 TECHNIQUES

Certain degrees of sandblasting* are required in each of the four classes of surface preparation. In addition to the degree of sandblasting, there is a dry or wet sandblasting technique that can be selected.

4.5.1.1 DRY SANDBLASTING. Consists of conventional and vacuum blasting.

a. Conventional blasting has the following characteristics:

(1) No effort to control dust or reclaim sand

(2) New construction or repair work in shop or field

* Other abrasives such as shot, grit, slag, fly ash, and alumina are used but are much less important in field work than sand. Sandblasting is probably the most versatile of the abrasive-blast cleaning methods.

(3) Critical areas (machinery, bearings, etc.) must be protected

(4) Dust must be removed by air, vacuum, or brush before painting

(5) Goggles and mask required.

b. Vacuum blasting has the following characteristics:

(1) Very efficient for repetitive, small-scale cleaning jobs in shops

(2) Less efficient in the field; creating the vacuum area is one problem; contaminants in reclaimed sand is another

(3) Costly and slow progress on bridge-type structures, *not suitable for antennas*

(4) Goggles and mask required.

4.5.1.2 WET BLASTING.

Wet blasting has the following characteristics:

a. It eliminates dust

b. Bridge structures with ledges, corners, pockets, crevices, etc., are not suitable for wet blasting. Wet sand is very difficult to remove from corners and pockets. *This method is not suitable for antennas.*

c. Corrosion subsequent to wet sandblasting is extremely difficult to control, even with rust inhibitor.

4.5.2 TECHNICAL DATA

There is no ideal method of cleaning all metals to prepare them for paint coatings; however, the most flexible and effective method is sandblasting or abrasive blasting. Sandblasting can rapidly clean corners and angles where no other techniques can be economically employed. Sandblasting also frosts the metal surface and facilitates good bonding of modern paint coatings. The sandblasted frost is called an Anchor Pattern. To obtain a properly sandblasted ferrous metal surface, a compressor capable of 100—125 psi, and, depending on the number of hoses in service and sandblaster nozzle size, 80 to 330 cubic feet per minute capacity is required. A remote control valve negates the need for a two-man team to sandblast. One professional sandblaster using the remote control valve with a deadman switch can sandblast with a great degree of safety and economy. The cleaning and etching that the sand achieves is the result of the size, the cutting angles, and the high-velocity impact of the abrasive grains. The venturi nozzle discharges sand at almost 450 miles per hour. It is important to remember that all sand grains are not suitable for sandblasting. The grain size and cutting angles should be specified. A fine angular silica sand "Ottawa" that will pass through a U. S. Standard Sieve No. 30 and rest on a U.S. No. 80 Sieve can effect a maximum profile height of 2.0 mils at 80 to 100 psi nozzle pressure. Refer to table 4-1.

In addition to the size, cut, and speed of the sand grain, the rate of cleaning depends on the number of sand grains discharged per unit of time; therefore, nozzle size is critical. If the proper air pressure (CFM) and hoses are used, nozzle size determines the area that can be cleaned per unit of time. Refer to table 4-2.

Table 4-1. Abrasive Data for Sandblasting* at 80—100 psi, 5/16-inch Diameter Nozzle

Abrasives	U. S. Sieve Series Screen Sizes	Cleaning Rate sq ft/min	Max profile height in mils
Large River Sand	Through U. S. 12 on U. S. 50	1.80 (estimate)	2.8
Medium Ottawa Silica Sand	Through U. S. 18 on U. S. 40	2.00 (estimate)	2.5
Fine Ottawa Silica Sand	Through U. S. 30 on U. S. 80	2.14	2.0
Very Fine Ottawa Silica Sand	Through U. S. 50, 80% through U. S. 100	2.15 (estimate)	Approx 1.0—1.5

*Courtesy of Steel Structures Painting Council (estimates by author)

Table 4-2. Cleaning Area Vs Nozzle Size

Venturi Nozzle	Previously Painted and Rusted Steel Surface Cleaned/Hour
1/4 in.	100 sq ft
5/16 in.	157 sq ft
3/8 in.	220 sq ft
7/16 in.	320 sq ft
1/2 in.	400 sq ft

The cost of sandblasting steel structures varies with the location, environment, type of structure, etc.; however, it is possible to cite the average experience as a guide to cost. (Refer to table 4-3.)

4.6 SOLVENT AND CHEMICAL CLEANING

4.6.1 SOLVENT

There are many solvents that will dissolve and carry away oils and greases. Solvents are important to surface cleaning because mineral oils such as hydraulic oils are insoluble in chemical alkali and acid type cleaners. Materials effective as solvents for cleaning structural steels are naphtha, toluene, turpentine, xylene, "Stoddard Solvent," and mineral spirits. The cleaning methods are wiping, brushing, and spraying. Solvents become contaminated quickly; therefore, before solvent cleaning begins, any excess greases, etc., should be mechanically removed by putty knives or scrapers. Solvent cleaning is dangerous as many of the agents are toxic and/or quite flammable. Benzene, gasoline, and carbon tetrachloride are not recommended for use as MSFN facilities cleaning agents. Much care should be exercised using solvents in temperatures between 85° and 95°F. At such temperatures a high flash point *aliphatic mineral spirits solvent* should be used. The use of solvents should be permitted only in areas of very good ventilation. Operators must be properly clothed to prevent the skin absorption of toxic levels of the solvent. All fire prevention rules should be followed. MIL-P-116 permits controlled cleaning by the use of solvents.

4.6.2 CHEMICAL

Alkali cleaning is less costly and less hazardous, but alkali is more difficult to apply than solvents because of the high temperature required (170—200°F). The soapy residues wash away with warm water. The most frequently used alkali cleaners are trisodium phosphate, caustic soda, or silicated alkalis. Any method of application seems satisfactory; tank cleaning is quite effective; but spray is also effective. Alkali cleaners should not be used

Table 4-3. The Cost of Sandblasting

Item	Cost		
	1/4" Nozzle	3/8" Nozzle	7/16" Nozzle
Approx Daily Cleaning Rate			
100 sq ft/hr	$ 0.25/sq ft	—	—
200 sq ft/hr	—	$ 0.15/sq ft	—
320 sq ft/hr	—	—	$ 0.13/sq ft
Rental Air Compressor			
125 CFM	$ 24.00/day	—	—
210 CFM	—	$ 38.00	—
315 CFM	—	—	$ 54.00
Abrasives (Table 4-1)			
$15/ton abrasive 6 hour blast/day	$ 27.00	$ 63.00	$ 90.00
Labor			
2 Operators @ $3.50/hr	$ 56.00	$ 56.00	$ 56.00
1 Operating engr. @ $4.50/hr	$ 44.00	$ 44.00	$ 44.00
Total Direct Costs			
Per day	$151.00	$201.00	$244.00
Per sq ft	$ 0.25	$ 0.15	$ 0.13

on aluminum or stainless steel except as an only possible method. Use a neutral detergent with a pH of 7.0 when cleaning aluminum or stainless steel; thorough rinsing is still required. *Every vestige of alkali must be rinsed from the surface* after cleaning, or it will destroy the adhesion of the new paint applications. Residual alkali can be detected by the application of pH test paper (litmus paper) to the wet surface. All alkali residue must be rinsed away quickly and completely; crevices must be rinsed thoroughly. Rinsing a complicated structure such as an antenna is quite demanding because of the joints, corners, pockets and hardware involved. If the alkali is permitted to dry before the rinsing, the task becomes much more difficult.

4.7 STEAM CLEANING

Steam cleaning (SSPC-SP1-63) is an extremely effective and rapid technique employing saturated steam between 100 and 200 pounds per square inch to soften and wash away some oils, greases, stains, and all water-soluble contaminants. The steam generators are usually once-through boilers with a feed water capacity of up to 5 gallons per minute. Steam cleaning is relatively inexpensive and as much as 30 times faster than hand cleaning. Steam cleaning may be the only feasible method at times to remove oils, greases, and stains in complicated structures such as antennas. In cases of very tenacious oils and/or dirts a nonfoaming detergent can be added to travel and impact with the steam; its strength should be determined by testing the tenacity of the dirt to be removed. Subsequent to the steam cleaning with detergent the structure should be rinsed thoroughly with clean water *to remove all traces of the alkali residue.* In addition to burns and scalds there are several inherent hazards when steam cleaning. For example, electrical wires, switchgear, and connections may require masking, and the masking cannot always be made adequate; consequently, water may enter expensive bearing races, etc. Exposed metal such as machined surfaces, gear teeth, switchgear, motors, etc., can be damaged either by accident or by unskilled personnel. Proper masking is of the utmost importance. Steam cleaning always precedes sandblasting when both are required because sandblasting will tend to drive pliable coatings such as waxes, oils, and greases into the surface of the metal. Regardless of the clean appearance of the metal, paint coats will not bond well to such contaminated substrates for an acceptable period of time.

4.8 PICKLING

Pickling (SSPC-SP8-63) uses an acid solution with solvent, detergent, and wetting agent. It is very effective on oil, grease, and foreign contaminants. It removes light rust and faintly etches the surface to permit better bonding. After acid cleaning, the surfaces should be rinsed immediately to avoid formation of salts which are difficult to remove. Pickling is one of the few effective methods of removing mill scale (figure 2-14) and some authorities feel it is the only method that truly cleans metal. Pickling of assembled antennas in the field is not possible.

4.9 PAINT REMOVERS

There are occasions in both spot repair painting and major repair painting where surface preparation requires the removal of the existing paint coats without the use of sandblast, needle gun, or other mechanical devices. At such times the correct approach may be the use of paint removers, as follows:

a. An alkali organic solvent can be used to remove paints from metal surfaces and silicate based materials. The effective reaction time may require 4 hours or more depending on types of paint, numbers of coats, and ages of the paint involved in addition to temperature and humidity. This type of paint remover can be washed off the metal with room-temperature water. Its brushing and spraying properties are satisfactory. Refer to TT-R-243.

b. An organic solvent can be used to remove paints from woods and metals. The residue must be scraped off. Type I is a flammable mixture with a paintable retardant. Class A has a low viscosity. The brushing properties are satisfactory. Refer to TT-R-251.

4.10 METAL CONDITIONERS

A phosphoric acid type compound that must be diluted to desired strength with water can be used as a metal conditioner. The metal conditioner dissolves rust and etches metal. Residue must be thoroughly washed off and surface dried before painting. Brushing and spraying properties are satisfactory. Refer to MIL-M-10578.

Surface preparation methods are quite numerous. For each surface condition there is one treatment or combination of treatments that is best for that particular job of surface preparation. In each instance the only purpose is to prepare a surface, either metal or aged paint, to receive a protective coating. Table 4-4 illustrates the great value of proper surface preparation in terms of life performance. Reasonable approximations of dollar costs and maintenance intervals can also be plotted by using this table. *The most important phase of a total painting system is surface preparation!*

Table 4-4. Environmental and Surface Preparation Impacts on Paint Life

Environment[1]	Class of Surface Preparation	Denotes High Probability of Paint Life Termination[2] — Years									
		1	2	3	4	5	6	7	8	9	10
Dry	I		▨	▨							
	II				▨	▨					
	III					▨	▨				
	IV							▨	▨	▨	▨
Normal	I		▨								
	II		▨	▨							
	III				▨	▨					
	IV					▨	▨				
Humid	I	▨									
	II	▨									
	III	▨	▨								
	IV		▨								
Harsh	I	▨									
	II	▨									
	III	▨									
	IV	▨	▨								

Notes

[1] Environments are defined for this study in table 2-4.

[2] The high probability of paint life termination with different classes of surface preparation in the various environments is formulated by considering actual antenna experience, test panel life, etc. Refer to glossary for MSFN paint life definition.

Note

Regardless of the type and degree of surface preparation, it is essential that the prepared metal surface be sealed or primed before any new deterioration takes place. In harsh environments, immediate sealing or priming is necessary. It is also necessary that the succeeding paint layers be applied to a very dry, clean surface. Surface preparation, therefore, includes the metallic substrate and the surface of each underlying paint.

PART C. PAINT COATINGS FOR METALLIC SURFACES

All ferrous metals, if not protected, corrode at a rate determined directly by the local environment. A very dry climate minimizes corrosion because it fails to provide an essential electrochemical ingredient, the electrolyte. A warm, moist, saline atmosphere encourages the most rapid type of corrosion because it provides an excellent electrolyte.

The total range of corrosion activity in natural environments lies between these extremes. Man-made industrial corrosive atmospheres of hydrogen sulfide, etc., also encourage deterioration rates of exposed and painted irons, steels, and other metals.

Note

The four types of environments encountered at the MSFN tracking stations are given in table 2-4. These four environments constitute the common denominator on which the recommendations for the type of paint coatings for the MSFN facilities are based.

To inhibit the corrosion of ferrous metals, man has turned to using protective paint coatings. Protective coatings are combinations of wash primer coats, primer coats, intermediate coats, and top coats. In some instances, the same material serves for both primer and top coats. There are hundreds of paints manufactured for a variety of purposes. Most paints consist essentially of a solvent, binder, and pigment; however, there are same high polymer, two-component paints that may not be de-

pendent upon a solvent. The performance characteristics of binders considered here are those that, when correctly selected for the environment and properly applied to properly prepared surfaces as detailed in this study, perform satisfactorily. The binder is that part of the vehicle which cements the pigment to the substrate after the thinners (solvents) have dried out. Binders are classed as organic or inorganic. Organic binders are numerous and have carbon in their chemistry; examples are linseed oil, alkyd, vinyl, chlorinated rubber, epoxy, and urethane. Inorganic binders are less numerous and have no carbon in their chemistry; an example is sodium silicate. The performance of various binders that might be considered for antenna corrosion control is expressed in qualitative terminology in table 4-5. Table 4-6 is a listing of the characteristics of paint binders.

Table 4-5. Performance of Paint Binders on Ferrous Metals

	Alkyd	Epoxy	Oil	Urethane Moisture Cured	Phenolic	Rubber	Vinyl
Solvent	M.S. [1]	See MIL-T-19544 MIL-T-19588	M.S.	Lacquer	M.S. + Arom [2]		Ester's Ketones
Minimum Surface Prep MSFN Antennas	Class III	Class IV	Class II	Class IV			
Adhesion + Bonding	Good	Excellent	Good	Excellent	Good		
Moisture Permeability	Mod	Low	Mod	Low			
Resistance to: Water Alkali Strong Solvents Abrasion	Fair Poor Poor Good	Good Excellent Excellent Excellent	Fair Poor Poor Poor	Excellent Good Excellent Excellent		Excellent Good Good Good	Excellent Good Good Excellent
Service: Normal Environment Harsh Environment	Good Not recom	Very good	Good Not recom	Very good Good		Good	Excellent
Paint Cost	Low	High	Mod	High	Mod		
Paint System Cost	Mod			High			Very High

Notes

[1] M.S. —Mineral Spirits
[2] Arom—Aromatic Hydrocarbons

Table 4-6. Characteristics of Paint Binders

1. LINSEED OIL

a. The old classic binder obtained from flax seed
b. Probably accepts more pigments than any other binder
c. High wetting power
d. High flexibility
e. Short life in harsh environment [1], poor resistance to alkalis

f. Satisfactory application by spray or brush
g. Easy to apply
h. Readily available
i. Dries by reacting with oxygen
j. Cannot serve as a base for lacquers, vinyls, etc. The paints with solvents will lift the oil binder type paints.

2. ALKYD

a. A synthetic binder
b. Made from glycerine and phthalic anhydride usually modified by fatty acids or drying oils
c. Dries by reacting with oxygen
d. Available in pigmented form
e. Gloss and color retention good

f. Easy to apply, easily maintained, tends to smudge easily
g. Any surface coated with an alkyd paint must be alkali free
h. Good performance in dry and normal environments
i. Intercoat adhesion problems may result if straight alkyd is applied over vinyl; alkyd may not bite into the vinyl.

3. VINYL

a. Resins are from copolymerized vinyl compounds
b. Vinyl chloride and vinyl acetate are main constituents of vinyl resin
c. High percentage of solvents, dries by evaporation of solvent
d. Vinyl thinners are MIK (methyl isobutyl ketone), toluene and xylene.
e. Resistant to most solvents except ketones and esters (the acetates and acetones)
f. Resistant to water and alcohol
g. Low percentage of solids requires many applications to build up system, difficult to achieve complete sealing of a surface with vinyl
h. Vinyl cannot be used over any rust or dirt of any type or degree.
i. Requires extensive surface preparation due to adhesion characteristics. Surface preparation of metal should be class IV.
j. Difficult to apply properly because of lifting (good craftsmanship a must!)

k. Vinyl wash primers and paints may be diluted as much as 1-to-1 with thinner to prevent spattering and to get an even flow. Test to determine proper dilution.
l. Cost is high due to many applications; vinyl systems should be built up of 0.5 to 1.0 mil layers. High-build vinyls, 2—3 mils per coat, are extremely difficult to achieve; some experts do not believe in high-build vinyls.
m. Durable in harsh environments
n. Not compatible with many aged paints. Use of a tie coat in between paint coats is possible at times; check manufacturer's recommendations.
o. Vinyls have tendency to bridge peaks of substrate when applied by spray. Some experts feel that brushing vinyl is better than air spraying.
p. Never use VR-3 directly on MIL-P-15328 or any polyvinyl butyral wash primer.
q. VMCH, VYHH, and VAGH are Union Carbide classifications. VMCH and VYHH vinyls are not compatible with wash primers. VAGH vinyl is compatible with wash primers and to some extent other paints. VMCH is the only vinyl that has bare metal adhesion.

4. VINYL ALKYD

a. Compromise between straight alkyd and vinyl, a combination of vinyl and alkyd resins
b. Cost is lower than vinyl
c. Easier application than vinyl

d. Requires pretreatment of surface; wash primer and zinc chromate
e. Apply by brush or spray
f. Durable top coat in dry and normal environments.

5. PHENOLIC

a. Pheno-formaldehyde resin
b. Available in pigmented colors or white
c. Dries by reacting with oxygen

d. Tested extensively in very humid environments
e. Primer for metal subject to fresh water immersion
f. Good performance in normal and humid environments.

6. EPOXY (Catalyzed)

a. Epoxy resin and polyamide type of hardener are good combination
b. Two components, mix just before use
c. Limited pot life, 4—8 hours; check manufacturer's labeling

d. Lifting problems on previously painted surfaces; compatibility [2] with other paint coats should be tested before general use
e. Film layer is thick, one or two coats usually suffice
f. May chalk rapidly when exposed to weather
g. Very resistant to abrasion, alkalis, solvents, and corrosion.

Table 4-6. Characteristics of Paint Binders (cont.)

7. EPOXY (Ester)

a. One-component paint b. Handles and dries similar to alkyds	c. Resistance is between that of alkyds and catalyzed epoxy d. Cost is about the same as the alkyd group.

8. URETHANE (Uralkyd)

a. Oil modified urethane b. Similar to alkyds in handling but more expensive c. Poor color retention	d. Hard, tough film e. Application critical for good adhesion f. More resistant to harsh environment than alkyds.

9. URETHANE (Catalyzed)

a. Two-component finishes b. Similar to, but more expensive than, catalyzed epoxies c. Cures more rapidly at lower temperatures than catalyzed epoxies	d. Produces very hard films with good water and acid resistance e. Less adhesion and alkali resistance than catalyzed epoxies.

10. URETHANE (Moisture Cured)

a. Reacts with air moisture to cure b. Single component paint but has properties of two-component finish c. Jelling of unused material begins in 2 hours d. Only full cans can be stored	e. Durable and corrosion resistant f. Adhesion is a problem g. Before any overcoating or recoating, the existing paint coat should be tested with urethane to determine any degree of incompatibility.[2]

11. CHLORINATED RUBBER

a. Synthetic resin b. Made by chlorinating natural rubber c. Must be applied to a clean substrate, whiteblast	d. Poor wetting power e. Serves for primer and top coats f. Aromatic solvents will dissolve chlorinated rubber.

12. INORGANIC BINDERS (Silicate, Phosphate, Silicone Zinc)

a. Good adhesion b. Long life c. Application by brush or spray d. Thick coatings will mud crack e. Abrasion resistant f. Often requires "tie" coat between inorganic coat and other type paint coats; check manufacturer's recommendations	g. Inert binding agent h. Comparatively low electrical resistance i. Inorganic zinc-rich films have very high concentration of pigment content; 90 to 95 percent zinc in dry film is not uncommon j. Silicones are high priced, used for painting high-temperature surfaces (up to 500°F).

Notes

[1] Refer to table 2-4.
[2] Refer to paragraph 4.20.

4.11 SALT-WATER TESTS

There is a marked difference between the corrosion attack on a buoy in sea water and an MSFN antenna in a harsh atmosphere, but the demands on the protective coating system in each case have many similarities. The United States Naval Civil Engineering Laboratory at Port Hueneme, California, has conducted some long-period test programs on coatings for the protection of mooring buoys. These tests, reported in Technical Report 531, "Protection of Mooring Buoys," evaluated the different binders. (Refer to tables 4-7 and 4-8.)

Table 4-7. Coating Test Data on Navy Buoys*

Coating System	Primer			Additional Coats			Total	Months of Service	Overall Rating
	Type	Coats	Thickness Mils	Type	No. of Coats	Thickness Mils	Thickness Mils		
Urethane	Urethane		2	Urethane	3	8	10	51	Fair To Good
Epoxy	Epoxy	1		Epoxies	2	7	11—12	49	Good
Epoxy Polyester			4—5	Polyester		5—6	9—11		Fair
Phenolic	Wash Primer Phenolic	1	.5	Phenolic	1	2—3	7—8	44	
Phenolic Alkyd		2	4.5	Alkyd					
Vinyl	Wash Primer Vinyl	1	.5	Vinyl Alkyd	3	4	11—12	45	Fair to Good
		4	6.5—7.5						
Inorganic Silicate Vinyl	Inorganic Zinc Silicate Vinyl Phenolic	1	4	Vinyl Mastic	1	5—6	10—12	51	Poor To Fair
Saran (formula 113/54)	——	——	——	Saran	——	8		50	Good

*Source: Technical Report R531 USN, June 1967.

Table 4-8. Ratings of Buoys With Test Coatings (Seacoast Atmosphere)*

Coating System	Months in Service	Color	Chalking	Blistering	Checking	Cracking	Scaling	Rusting without Blistering	Rusting with Blistering
Urethane	51		4	F	9				
Epoxy									
Epoxy Polyester	49		8				10		
Phenolic		9	6	N		10		9	10
Phenolic Alkyd	44		4		10				
Vinyl	45						N, 10		
Inorganic Zinc Silicate Vinyl	51		10				10		
Vinyl Saran (formula 113/54)	50							8	

Notes

Rating Scale:
  10—perfect condition
  0—complete deteriortion

Blistering Frequency
  N—none
  F—few

*Source—Technical Report

4.12 SELECTING THE CORRECT PAINT

The challenge of selecting the proper paint for some specific job is a formidable one. It is even more challenging when the painting concerns the antennas of the MSFN tracking stations because corrosion protection, esthetics, thermal effects, hostile environments, electronic effects, surface preparation limitations, mission requirements, etc. must be considered. There are control specifications to ensure that the proper ingredients are in a certain paint. There are the federal (TT) and military (MIL) specifications, which should be used to qualify paints that will be applied to antennas. It must be stated, however, that because of the complexity of many paints, such as those with the newer organic and inorganic binders, there can be coatings that meet the military specifications and yet not be the best paints available in the grouping.

Another definite problem is verification of whether a paint fulfills the military or federal specifications as claimed by the maker. The long time delay in obtaining independent laboratory analysis of paints labeled as meeting military or federal specifications negates the usefulness of the analysis because the report is often received after the completion of the work. In addition, quantitative and qualitative analyses of paints are quite expensive. In general, several points should caution and guide the engineer when selecting paints for the antennas and facilities:

a. There are no ideal paints for any exposed surface. The best selection of a paint system is always a compromise involving the environment, metals, structure complexity, thermal requirements, time, surface preparation, previous paint system, painting cycle, corrosion, money, craftsmanship, and electronic criteria.

b. Regardless of paint quality and application techniques, none of the organic or inorganic paint systems can totally seal out vapor; a slow permeation takes place.

c. High performance by top quality paints of today depends upon a high level of craftsmanship and inspection.

d. All the conditions that affect the use and life of protective coating systems at the MSFN tracking stations are discussed in this study.

e. Tables 4-9 through 4-17 specify the proper paint systems to be used in the different MSFN tracking station environments.

4.13 PAINTING IRONS AND STEELS

Refer to tables 4-9 through 4-13.

4.14 PAINTING ALUMINUM

Painting aluminum requires attention to several details, as paints will not properly bond to unprepared aluminum surfaces. Refer to tables 4-15 and 4-16.

4.14.1 SURFACE PREPARATIONS

a. Solvents—use to dissolve tenacious oils and greases, must be followed by steam cleaning (shop or field)

b. Steam cleaning—use without detergent, if possible, to remove dirt and oils; if detergent is necessary, use one with a pH of 7.0. Any detergent used must be removed quickly and completely (field use).

c. Light sandblasting—use to achieve a uniform frosting effect or low profile (field use)

d. Alkaline solution—very fast, very difficult to rinse off (shop use)

e. Acid solution—less effective than alkaline solution (shop use)

f. Chemical conversion coatings—
    (1) Crystalline phosphate (shop use)
    (2) Amorphous phosphate coatings—good base for organic coating (can be used in the field)
    (3) Amorphorus chromate—good base for painting (can be used in the field).

4.14.2 PAINTS THAT CAN BE APPLIED TO PROPERLY PREPARED ALUMINUM

4.14.2.1 PRIMERS

a. Polyvinyl butyral wash primer. MIL-P-15328 is two-component type; MIL-P-14504 is one-component type. Etches surface to make base for organic coatings. Should be thinned up to 1-to-1 with proper alcohol

b. Alkyd type zinc chromate (TT-P-645). Inhibitive primer to prevent corrosion of substrate

c. Alkyd and epoxy resins. Good adherence to properly prepared aluminum.

4.14.2.2 TOP COATS

a. Alkyds, phthalate alkyds. Air dry finishes that, when properly pigmented, have good outdoor life

b. Acrylics, resins based on acrylic acids. Resistance in high humidity is fair

c. Vinyls, polyvinyl chloride. Good resistance to corrosion

d. Epoxy resins. Outstanding chemical resistance.

4.14.3 FIELD PAINTING ALUMINUM AT THE MSFN TRACKING STATIONS*

When painting aluminum in the field, proper attention should be given to the paint manufacturer's instructions on mixing, compatibilities, and proper curing.

a. Remove oils and greases with solvents.

b. Steam clean and dry (use 24 psi steam).

c. Light sandblast to low profile. (Omit if aluminum is too thin or old paint system is in good shape.)

d. Spray bare metal with polyvinyl butyral MIL-P-15328, 0.2—0.5 mils per coat, one coat only. Refer to note 4, page 4-15.

e. Intermediate coat is zinc chromate.

f. Alkyd top coat for dry and normal environment, two coats 0.8—1.2 mils per coat.

g. Vinyl top for normal, humid, and harsh environments, 0.8—1.2 mils per coat.†

4.15 PAINTING GALVANIZED STEELS††

Zinc (galvanized) surfaces present some formidable problems to painting if ordinary paint systems are used. New zinc and, to a much lesser extent, old zinc reacts with ordinary paints and results in peeling and flaking. The home-cure type of treatments to prepare a galvanized surface for painting, such as washing the surface with vinegar, acetic acid, cider, copper sulfate solutions, muriatic acid, or hydrochloric acid, have proved fairly useless. There is another pitfall in painting galvanized metal—some of the excellent paint systems for galvanized surfaces are ineffective if the surface has been chemically treated at the mill to prevent humid storage stain.

Regardless of the problems in painting galvanized surfaces, several proven paint systems perform an excellent job. For example:

a. Hot phosphate (bonderizing) paint pretreatments convert the surface to zinc phosphate. Hot phosphate pretreatment is detailed in TT-C-490, "Cleaning and Preparation of Ferrous and Zinc Coated Surfaces from Organic Protective Coatings," and in SSPC-PT4-64, "Hot Phosphate Surface Treatment."

⟨ CAUTION ⟩

If a galvanized surface has been treated at the mill to prevent humid storage stain, the hot phosphate treatment should not be used.

* Refer to table 4-15.
† Refer to vinyl warning g. under heading Vinyl, table 4-6.
†† Refer to table 4-14.

Environment [1]	Minimum Surface Preparation Recommended	Paint System	Paint Coats [3]				Remarks
			Pretreatment	Primer	Intermediate If Required	Top	
Dry	Class III [2]	Alkyd	MIL-P-15328.[4] Polyvinyl butyral/ basic zinc chromate 0.2—0.5 mil, 1 coat	TT-P-645. Alkyd zinc chromate 1.2—1.5 mils, 1 coat Σ min 1.4 mils	TT-E-489. Alkyd/titanium dioxide 1.2—1.5 mils per coat, 1 coat, Σ min 2.6 mils	TT-E-489. Alkyd/titanium dioxide 1.2—1.5 mils per coat, 2—3 coats, Σ min 3.8 mils	Also good system for painting aluminum
					TT-E-490. Silicone alkyd/ titanium dioxide 1.2—1.5 mils per coat, 1 coat, Σ min 2.6 mils	TT-E-490. Silicone alkyd/ titanium dioxide 1.2—1.5 mils per coat, 2—3 coats, Σ min 3.8 mils	Semigloss white, resistant to yellowing
		Vinyl alkyd		TT-P-86. Type III alkyd varnish/red lead 1.2—1.5 mils, 1 coat, Σ min 1.4 mils	MIL-E-16738. Vinyl alkyd/ titanium dioxide 1.2—1.5 mils per coat, 1 coat, Σ min 2.6 mils	MIL-E-16738. Vinyl alkyd/ titanium dioxide 1.2—1.5 mils per coat, 2—3 coats, Σ min 3.8 mils	MIL-E-16738 must dry for 24—36 hours before top coating with MIL-E-16738, danger of lifting if not dry

Notes

[1] For definition of environments, refer to table 2-4.
[2] Surface preparations are detailed in Chapter IV, Part B.
[3] Series of paint coats must vary in color to permit visual inspection.
[4] MIL-P-15328 is a two-component paint, 4 gallons of base in a 5 gallon container, 1 gallon of acid component in plastic container. Prior to adding the acid, the base should be well stirred, as it tends to settle. Prior to addition to the base, the acid component should be diluted up to 1-to-1 with isopropyl alcohol to prevent jelling. Add alcohol slowly and agitate constantly. Mix and test to produce the quality and quantity of film desired.

Table 4-10. Paint Systems for Exterior Irons and Steels—Dry or Normal Environment

Environment [1]	Minimum Surface Preparation Recommended	Paint System	Paint Coats				Remarks
			Pretreatment	Primer	Intermediate If Required	Top	
Dry or Normal	Class III	Alkyd or Silicone alkyd	MIL-P-15328. [2] Polyvinyl butyral/ basic zinc chromate or MIL-P-14504. Polyvinyl butyral/ chromate 0.2—0.5 mil, 1 coat	TT-P-57. Type II alkyd/zinc yellow iron oxide or TT-P-86. Type III alkyd varnish/red lead or TT-P-615. Type III alkyd varnish/lead silico chromate or TT-P-645. Alkyd/zinc chromate 1.2—1.5 mils per coat, 1 coat Σ min 1.4 mils	TT-E-489. Alkyd/titanium dioxide 1.2—1.5 mils per coat, Σ min 2.6 mils	TT-E-489. Alkyd/titanium dioxide 1.2—1.5 mils per coat, 2—4 coats Σ min 6—8 mils	Gloss white finish
					TT-E-490. Silicone alkyd/ titanium dioxide 1.2—1.5 mils per coat, Σ min 2.6 mils	TT-E-490. Silicone alkyd/ titanium dioxide 1.2—1.5 mils per coat, 2—4 coats Σ min 6—8 mils	Semigloss white, resistant to yellowing
					TT-E-527. Alkyd/titanium dioxide 1.2—1.5 mils per coat, Σ min 2.6 mils	TT-E-527. Alkyd/titanium dioxide 1.2—1.5 mils per coat, 2—4 coats Σ min 6—8 mils	Lusterless white

Notes

[1] For definition of environments, refer to table 2-4.
[2] Refer to note 4, page 4-15.

Table 4-11. Paint Systems for Exterior Irons and Steels—Humid Environment

Environment [1]	Minimum Surface Preparation Recommended	Paint System	Paint Coats				Remarks
			Pretreatment	Primer [2]	Intermediate If Required	Top	
Humid	Class IV	Phenolic or Phenolic alkyd	MIL-P-15328.[4] Polyvinyl butyral/ basic zinc chromate or MIL-P-14504. Polyvinyl butyral/ chromates 0.2—0.5 mil, 1 coat	TT-P-57. Type III Phenolic varnish/zinc yellow-iron oxide 1.0—2.0 mils per coat, 2 coats, Σ min 3 mils	TT-P-38. Phenolic resin varnish/aluminum 1.0—2.0 mils per coat, 1 coat, Σ min 4.5 mils	TT-P-38. Phenolic resin varnish/aluminum 1.0—2.0 mils per coat, 2—4 coats, Σ min 8—9 mils	Aluminum colored finish
				TT-P-86. Type IV Phenolic varnish/red lead 1.0—2.0 mils per coat, 2 coats, Σ min 3 mils	TT-P-522. Phenolic/titanium dioxide 1.0—2.0 mils per coat, 1 coat, Σ min 4.5 mils	TT-E-522. Phenolic/titanium dioxide 1.0—2.0 mils per coat, 2—4 coats, Σ min 8—9 mils	White lusterless, may tend to yellow
				TT-P-615.[3] Type IV Phenolic varnish/lead silico chromate 1.0—2.0 mils per coat, 2 coats, Σ min 3 mils	TT-E-490. Silicone alkyd/ titanium dioxide 1.0—2.0 mils per coat, 1 coat, Σ min 4.5 mils	TT-E-490. Silicone alkyd/ titanium dioxide 1.0—2.0 mils per coat, 2—4 coats, Σ min 8—9 mils	Semigloss white, resistant to yellowing

Notes

[1] For definition of environments, refer to table 2-4.
[2] Note increased primer protection for humid environments.
[3] Check manufacturer agent on tie coat requirement between TT-P-615 and TT-E-490.
[4] Refer to note 4, page 4-15.

Table 4-11. Paint Systems for Exterior Irons and Steels—Humid Environment (cont.)

| Environment [1] | Minimum Surface Preparation Recommended | Paint System | Paint Coats | | | | Remarks |
			Pretreatment	Primer	Intermediate If Required	Top	
Humid [2]	Class IV	Vinyl alkyd	MIL-P-15328.[4] Polyvinyl butyral/ basic zinc chromate 0.2—0.5 mil, 1 coat	MIL-P-15929. Vinyl/red lead 0.5—1.0 mil per coat, 2—3 coats, Σ min 2 mils	MIL-E-16738. Vinyl alkyd/ titanium dioxide or VR-3 1.0—1.5 mils per coat, 1 coat, Σ min 3 mils	MIL-E-16738. Vinyl alkyd/ titanium dioxide or VR-3, 1.0—1.5 mils per coat, 3—4 coats, Σ min 8—10 mils	Semigloss white
		Organic zinc rich and Silicone alkyd	None [3]	MIL-P-26915. Organic/zinc dust Type I 1.5—2.5 mils per coat, 2—3 coats, Σ min 5 mils	Use tie coat recommended by the manufacturer of the organic zinc primer 1.2—1.5 mils per coat, 1 coat, Σ min 6.5 mils	TT-E-490. Silicone alkyd/ titanium dioxide 1.0—1.5 mils per coat, 2—3 coats, Σ min 10—12 mils	Semigloss white, resistant to yellowing

Notes

[1] For definition of environments, refer to table 2-4.
[2] In humid environments, a properly prepared surface can become contaminated within minutes which will prevent proper adherence of paint.
[3] Zinc rich paint provides both barrier and cathodic type protection for steel, therefore, no pretreatment is used.
[4] Refer to note 4, page 4-15.

Environment [1]	Minimum Surface Preparation Recommended	Paint System	Paint Coats [1]				Remarks
			Pretreatment	Primer	Intermediate If Required	Top	
Humid or Harsh	Class IV [2]	Vinyl acrylic [3]	MIL-P-15328. [4] Polyvinyl butyral/ basic zinc chromate 0.2—0.5 mil, 1 coat	MIL-P-15929. Vinyl/red lead 0.8—1.0 mil per coat, 2—3 coats, Σ min 3 mils	Vinyl acrylic/ titanium dioxide 0.8—1.0 mil per coat, 1 coat, Σ min 4 mils	Vinyl acrylic/ titanium dioxide 0.5—1.0 mil per coat, 3—5 coats, Σ min 8—9 mils	Semigloss white
		Alkyd and silicone alkyd		TT-P-641. Type II alkyd resin/zinc dust 1.5—2.5 mils per coat, 2—3 coats, Σ min 4 mils	TT-E-490. Silicone alkyd/ titanium dioxide 1.0—1.5 mils per coat, 1 coat, Σ min 5 mils	TT-E-490. Silicone alkyd/ titanium dioxide 1.0—1.5 mils per coat, 2—3 coats, Σ min 8—9 mils	Semigloss white, resistant to yellowing
		Organic zinc rich and epoxy ester	None	MIL-P-26915. Type I Class A epoxy ester/zinc dust 0.6—1.4 mils per dry film coat, 2 coats, minimum 8 hours between coats	No MIL Spec Epoxy ester/ titanium dioxide 0.6—1.2 mils per dry film coat, 1 coat	No MIL Spec Epoxy ester/ titanium dioxide 0.8—1.5 mils per dry film coat, 1 coat	Epoxy esters cure properly in temperatures from 50 to 100°F. Epoxies should not be applied to cold surfaces.
		Organic zinc rich and epoxy ester	None		VR-3/titanium dioxide 0.3—0.6 mils per dry film coat, 2 coats 4 hours between coats	VR-3/titanium dioxide 0.5—1.0 mil per dry film coat 1 or 2 coats 4 hours between coats	Caution: Epoxy ester zinc dust must completely cure before vinyl is applied. Cure time is 8 days minimum.

Notes

[1] For definition of environments, refer to table 2-4.
[2] Surface preparations are detailed in Chapter IV, Part B.
[3] No military or federal specification on vinyl acrylic as of Jan. 1, 1969.
[4] Refer to note 4, page 4-15.

Table 4-13. Paint Systems for Exterior Irons and Steels—Harsh Environment

Environment [1]	Minimum Surface Preparation Recommended	Paint System	Paint Coats				Remarks
			Pretreatment	Primer	Intermediate If Required	Top	
Harsh	Class IV	Organic zinc rich and vinyl	None	Corps of Engineers [3] Spec. VZ 107. Vinyl/zinc dust 1.5—2.0 mils per coat, 2 coats, Σ min 3 mils	VR-3. Vinyl/titanium dioxide 0.8—1.0 mil per coat, 1 coat, Σ min 3.8 mils	VR-3. Vinyl/titanium dioxide 0.8—1.0 mil per coat, 3—5 coats, Σ min 8—9 mils	Always check manufacturer's instructions on compatibility of vinyls. [2]
		Inorganic zinc rich and vinyl		MIL-P-38336. Inorganic/zinc or MIL-P-23236. Inorganic/zinc 2.0—3.0 mils per coat, 1—2 coats, Σ min 5 mils	Check manufacturer's recommendations for tie coat requirements for compatibility. 1.2—1.5 mils per coat, 1 coat, Σ min 6.5 mils	VR-3. Vinyl/titanium dioxide 0.8—1.0 mil per coat, 3—4 coats, Σ min 10—11 mils	White, system will mud crack if coatings are too thick. [2]
		Inorganic zinc and urethane		MIL-P-38336. Inorganic/zinc or MIL-P-23236. Inorganic/zinc 2.0—3.0 mils per coat, 1—2 coats, Σ min 5 mils	Check recommendations for tie coat requirements for compatibility. 1.2—1.5 mils per coat, 1 coat, Σ min 6.5 mils	MIL-C-38427. Urethane/titanium dioxide Type II Class 1 1.5—3.0 mils per coat, 1—2 coats, Σ min 10—11 mils	White, may chalk and/or yellow when exposed.

Notes

[1] For definition of environments, refer to table 2-4.
[2] Certain vinyls are not compatible even with other vinyls.
[3] Civil Works.

Environment [1]	Minimum Surface Preparation Recommended	Paint [2] System	Paint Coats				Remarks
			Pretreatment	Primer	Intermediate If Required	Top	
Harsh	Class IV	Inorganic zinc rich and vinyl alkyd	None	MIL-P-38336. Inorganic/zinc or MIL-P-23236. Inorganic/zinc 2—3 mils per coat, 1—2 coats, Σ min 5 mils	Check with manufacturer for tie coat requirements for compatibility. 1.2—1.5 mils per coat, 1 coat, Σ min 6.5 mils	MIL-E-16738. Vinyl alkyd/ titanium dioxide 1.0—1.5 mils per coat, 3—4 coats, Σ min 10—11 mils	White, see MIL-E-15932 through MIL-E-15936 for other colors.
		Epoxy	MIL-P-15328. [3] Polyvinyl butyral/ basic zinc chromate 0.2—0.5 mil, 1 coat	MIL-P-23377. Epoxy polyamide titanium dioxide 1.5—2.0 mils per coat, 2 coats, Σ min 3.5 mils	MIL-C-22750. Epoxy polyamide 1.5—2.0 mils per coat, 1 coat, Σ min 5 mils	MIL-C-22750. Epoxy polyamide 1.5—2.0 mils per coat, 2 coats, Σ min 8—9 mils	Very hard surface, epoxy may chalk when exposed, may develop inner coat adhesion problems.
		Inorganic zinc rich and epoxy	None	MIL-P-38336. Inorganic/zinc 1.5—2.0 mils per coat, 1—2 coats, Σ min 3 mils	Check with manufacturer for tie coat requirements for compatibility. 1.2—1.5 mils per coat, 1 coat, Σ min 4.5 mils	MIL-C-22750. Epoxy polyamide 1.5—2.0 mils per coat, 2 coats, Σ min 8—9 mils	Always check manufacturer's label for compatibility of different paints.

Notes

[1] For definition of environments, refer to table 2-4.
[2] Constant quality control by a knowledgeable inspector is a requirement of major paint work on the MSFN antennas.
[3] Refer to note 4, page 4-15.

Table 4-13.   Paint Systems for Exterior Irons and Steels—Harsh Environment (cont.)

Environment [1]	Minimum Surface Preparation Recommended	Paint System	Paint Coats [3]				Remarks
			Pretreatment	Primer	Intermediate If Required	Top	
Harsh	Class IV	Vinyl [2]	MIL-P-15328. [4] Polyvinyl butyral/ basic zinc chromate 0.2—0.5 mil per coat, 1 coat	MIL-P-15929. Vinyl/red lead 0.5—1.0 mil per coat, 2—3 coats, Σ min 2 mils	VR-3. Vinyl/titanium dioxide, gray color 0.8—1.2 mils per coat, 1 coat, Σ min 3 mils	VR-3. Vinyl/titanium dioxide, white with violet toner 0.8—1.2 mils per coat, 4—5 coats, Σ min 8—9 mils	Finish coats T_1O_2 pigment with violet toner or ultra violet light absorber. Any VMCH, VAGH, or VYHH vehicle with plasticizer. Also good system for salt water immersion!
			None	VR-3. Vinyl/iron oxide 0.8—1.2 mils per coat, 1 coat, Σ min 1.0 mils	VR-3. Vinyl/titanium dioxide gray 0.8—1.2 mils per coat, 1 coat, Σ min 2 mils	VR-3. Vinyl/titanium dioxide white, iron oxide gray, white 0.8—1.2 mils per coat, 5—6 coats, Σ min 7—8 mils	Expensive but good system, surface condition for painting with vinyl is very critical, also good system for freshwater immersion.

Notes

[1] For definition of environments, refer to table 2-4.
[2] Vinyls have strong tendency to liver and lump if too thick.   Always spray test plate and dilute vinyl as required to achieve smooth cover.
[3] Alternating colors as the paint system is built up permits good visual inspection of paint application.
[4] Refer to note 4, page 4-15.

Table 4-14. Paint Systems for Exterior Galvanized Steel—All Environments

Environment [1]	Minimum [2] Surface Preparation Recommended	Paint System	Paint Coats				Remarks
			Pretreatment [3]	Primer	Intermediate If Required	Top	
Dry, Normal, Humid, or Harsh	Light cleaning to remove contaminants from zinc	Oil [4]	MIL-P-15328. [5] Polyvinyl butyral/ basic zinc chromate 0.2—0.5 mil per coat, 1 coat	TT-P-641. Type I linseed/zinc dust-zinc oxide 1.5—2.0 mils per coat, 1 coat, Σ min 1.5 mils	Any oil or oil alkyd paint except aluminum 1.5—2.0 mils per coat, 1 coat, Σ min 3 mils	Any oil or oil alkyd paint except aluminum 1.5—2.0 mils per coat, 2—3 coats, Σ min 9—10 mils	Also good for spot repair work
		Alkyd		TT-P-641. Type II phthalic alkyd/zinc dust-zinc oxide 1.5—2.0 mils per coat, 1 coat, Σ min 1.5 mils	TT-E-489. Alkyd/titanium dioxide 1.5—2.0 mils per coat, 1 coat, Σ min 3 mils	TT-E-489. Alkyd/titanium dioxide 1.5—2.0 mils per coat, 2—3 coats, Σ min 8—9 mils	Gloss white
					TT-E-490. Silicone alkyd/ titanium dioxide 1.5—2.0 mils per coat, 1 coat, Σ min 3 mils	TT-E-490. Silicone alkyd/ titanium dioxide 1.5—2.0 mils per coat, 2—3 coats Σ min 8—9 mils	Semigloss white, resistant to yellowing

Notes

[1] For definition of environments, refer to table 2-4.
[2] Refer to paragraph 4-15.
[3] Only a few paints will adhere to galvanized metals for a suitable period of time; for most paints a pretreatment of the galvanize is required.
[4] Oil paint systems require a long drying time between coats. There is danger from humidity, rain, etc., between coats. If applied too heavily, there is danger of wrinkling. Oil systems require more total dried film thickness than alkyd (at least 2—3 mils) in a seacoast or harsh environment.
[5] Refer to note 4, page 4-15.

Table 4-15. Paint System for Exterior Aluminum[2]—All Environments

Environment [1]	Minimum Surface Preparation Recommended	Paint System	Paint Coats				Remarks
			Pretreatment	Primer	Intermediate If Required	Top	
Dry, Normal, Humid, or Harsh	Light cleaning to remove contaminants from aluminum	Alkyd	MIL-C-8514. Polyvinyl butyral/ zinc chromate 0.2—0.5 mil per coat, 1 coat May require thinning to get thin even coat and prevent jelling. Test!	MIL-P-8585. Alkyd/zinc chromate 0.8—1.0 mil per coat, 1—2 coats, Σ min 2 mils	MIL-E-7729. Type I 1.5—2.0 mils per coat, 1 coat, Σ min 3.5 mils	MIL-E-7729. Type I 1.5—2.0 mils per coat, 1—2 coats Σ min 7—8 mils	Gloss white enamel & 16 colors [3]
					TT-E-490. Silicone alkyd/ titanium dioxide 1.5—2.0 mils per coat, 1 coat, Σ min 3.5 mils	TT-E-490. Silicone alkyd/ titanium dioxide 1.5—2.0 mils per coat, 1—2 coats, Σ min 7—8 mils	Semigloss [3] white, resistant to yellowing

Notes

[1] For definition of environments, refer to table 2-4.
[2] Many paint coats will *not adhere properly* to aluminun for an acceptable time.
[3] Also refer to high reflective paint system for aluminum in table 4-16.

Table 4-16. Paint Systems for Exterior Aluminum Reflectors—All Environments

| Environment [1] | Minimum Surface Preparation Recommended | Paint [2] System | Paint Coats | | | | Remarks |
			Pretreatment	Primer	Intermediate If Required	Top	
Dry, Normal, Humid, or Harsh	Solvent clean grease or oil spots. Steam clean with 25 psi steam.	Alkyd [2]	MIL-C-8514. Polyvinyl butyral/ zinc chromate 0.2—0.5 mil per coat, 1 coat May require thinning to get thin even coat and prevent jelling. Test!	MIL-P-8585. Alkyd/zinc chromate 0.8—1.0 mil per coat, 1—2 coats, Σ min 1.0 mil	No MIL Spec Triangle #6. [3] Castor oil-alkyd/ titanium dioxide- zinc oxide-zinc soap-diatomaceous silica-mercury 1.2—1.5 mils per coat, 1 coat, Σ min 2.2 mils	No MIL Spec Triangle #6. [3] Castor oil-alkyd/ titanium dioxide- zinc oxide-zinc soap-diatomaceous silica-mercury 1.2—1.5 mils per coat, 1—2 coats, Σ min 4 mils	High reflective flat white For overcoating an aged system of Triangle #6: 1. Repair the spots as per original system. 2. Steam clean lightly. 3. Apply Triangle #6 diluted 10% directly to cleaned aged paint.

Notes

[1] For definition of environments, refer to table 2-4.
[2] Special system for aluminum reflectors.
[3] This high reflective paint can also be used on ferrous metals properly primed.

Table 4-17. Paint Systems for Exterior Spot Repairs[4]—All Environments

Environment [1]	Minimum [2] Surface Preparation Recommended	Paint [3] System	Paint Coats				Remarks
			Pretreatment	Primer	Intermediate If Required	Top	
Dry, Normal, Humid, or Harsh	Class II	Oil or Oil alkyd	Unnecessary because primers specified have good wetting power	TT-P-57. Type I linseed alkyd/zinc yellow-iron oxide or TT-P-86. Type I linseed/red lead Type II alkyd varnish linseed/red lead or TT-P-615. Type I linseed alkyd/lead silico chromate 1.5—2.0 mils per coat, 1—2 coats,	TT-P-59. Linseed alkyd/ molybdate 1.5—2.0 mils per coat, 1 coat, Σ min 3.0 mils	TT-P-59. Linseed alkyd/ molybdate 1.5—2.0 mils per coat, 1—2 coats, Σ min 6—8 mils	International orange
					TT-P-81. Linseed alkyd/lead zinc 1.5—2.0 mils per coat, 1 coat, Σ min 3.0 mils	TT-P-81. Linseed alkyd/lead zinc 1.5—2.0 mils per coat, 1—2 coats, Σ min 6—8 mils	Medium shades
					TT-P-102. [5] Class B Linseed/titanium-lead-zinc 1.5—2.0 mils per coat, 1 coat, Σ min 3.0 mils	TT-P-102. [5] Class A Linseed/titanium-lead-zinc 1.5—2.0 mils per coat, 1—2 coats, Σ min 6—8 mils	Class B, tinted Class A, white
					TT-P-105. [5] Linseed/zinc oxide-titanium dioxide 1.5—2.0 mils per coat, 1 coat, Σ min 3 mils	TT-P-105. [5] Linseed/zinc oxide-titanium dioxide 1.5—2.0 mils per coat, 1—2 coats, Σ min 6—8 mils	Chalk free whites and tints

Notes

[1] For definition of environments, refer to table 2-4.
[2] Surface preparations are detailed in Chapter IV, Part B.
[3] The original paint system is often too complex to use as interim spot repair work by station personnel. In lieu of the original system, another system, usually with single component paints that have good wetting power, is often used.
[4] Refer to item on spot repairs, paragraph 4-19.
[5] Refer to note 4, page 4-15.

Environment [1]	Minimum [2] Surface Preparation Recommended	Paint System	Paint Coats				Remarks
			Pretreatment	Primer	Intermediate If Required	Top	
Dry, Normal, Humid, or Harsh	Class II	Fish oil and linseed oil or oil and alkyd	Unnecessary for spot repair work because primers specified have good wetting power	TT-C-530. [3] Fish oil/red iron oxide 1.5—2.0 mils per coat, 1—2 coats, Σ min 1.5 mils	TT-P-105. [3] Linseed/zinc oxide-titanium dioxide 1.5—2.0 mils per coat, 1 coat, Σ min 3 mils	TT-P-105. [3] Linseed/zinc oxide/titanium dioxide 1.5—2.0 mils per coat, 1—2 coats, Σ min 6 mils	Fish oil, linseed oil, and oil modified binders can be used on top of almost any aged paint system. This fact coupled with ease of application and good tolerances for substrate condition because of wetting power makes such paints acceptable for spot repairs.
				TT-E-485. [3] Type I oil alkyd/ chrome yellow-red lead-zinc oxide 2.0—3.0 mils per coat, 1 coat, Σ min 2 mils	TP-P-105. [3] Linseed/zinc oxide-titanium dioxide 1.5—2.0 mils per coat, 1 coat, Σ min 3.5 mils	TT-P-105. [3] Linseed/zinc oxide-titanium dioxide 1.5—2.0 mils per coat, 1—2 coats, Σ min 6 mils	

Notes

[1] For definition of environments refer to table 2-4.
[2] Refer to paragraph 4.19.2 for details on surface preparation.
[3] Refer to note 4, page 4-15.

b. Recent developments for use at the mill or on large production runs assure very good paintability of galvanized steel:

    (1) Chromate conversion coating

    (2) Amorphous film of complex oxides.

c. Wash primers, used freshly mixed, assure good paintability of galvanized steel. This process is detailed in SSPC-PT3-64, "Basic Zinc Chromate-Vinyl Butyral Washcoat."

The American Iron and Steel Institute has done much good work on the paintability of galvanized steels and has issued several general conclusions, as follows:

a. Zinc dust paints do very well on galvanize. (Refer to TT-P-641.)

b. Specially formulated zinc-dust paints and portland cement-in-oil paints perform well on galvanized sheet. The sheet can be either chemically treated at the mill against humid storage stain or not, and the above paints will perform satisfactorily.

c. Cement-in-oil paints must be carefully formulated. They perform well when top coated.

d. Proprietary paints vary in performance on galvanized steel. (Test before use to make certain.)

In conclusion, it appears that because of the high cost of corrosion, inaccessibility to effect repairs, and the operational necessity of continuous performance, galvanized steel offers much as structural material.* In addition, galvanized steel serves as an excellent substrate for the proper paint system.†

4.16 PAINTING MAGNESIUM

As with all types of painting the best advice that can be given on painting magnesium is that surface preparation largely determines the quality of the paint system. All grease and dirt must be removed by light steam cleaning and rinsing. The bond of paint on magnesium is determined to a great extent by the alkalinity of the protective film which forms on magnesium exposed to the atmosphere. It is good practice, therefore, to neutralize the alkaline magnesium surface with a Dow treatment, such as DOW No. 19. Painting magnesium

in the four MSFN environments should be as follows:

a. *Dry Environment*

    (1) Chemical treatments—DOW No. 1, 19, or 21

    (2) Primer—zinc chromate, one coat 0.5 mil, MIL-P-8585

    (3) Top coat—alkyd, two or more coats 0.5 to 1.0 mil per coat, TT-E-489 or any organic top coat compatible with primer.

b. *Normal Environment*

    (1) Chemical treatment—DOW No. 1, 7, 17,† 19, or 21

    (2) Primer—zinc chromate, one coat 0.5 mil, MIL-P-8585

    (3) Top coat—alkyd or silicone alkyd, TT-E-489 or TT-E-490, two or more coats, 0.5 to 1.0 mil per coat.

c. *Humid Environment*

    (1) Chemical treatments—DOW No. 1, 7, 17†, or 19

    (2) Primer—phenolic binder with titanium dioxide pigment, 1.0 mil, TT-E-522

    (3) Top coat—two or more coats of TT-E-522, 1.0 mil per coat.

d. *Harsh Environment*

    (1) Chemical treatment—DOW No. 7 or 17†

    (2) Primer—phenolic binder with titanium dioxide pigment, 1.0 mil, TT-E-522

    (3) Top coats—two or more coats of TT-E-522, 1.0 mil per coat

    (4) Dry baking preferred for harsh environment. (Use of magnesium in harsh environments is not recommended.)

Although magnesium alloys do have much to offer as light structural metals, they must be regarded as quite susceptible to corrosion in harsh environments. A careful investigation should be made before magnesium members are specified for new or replacement parts in MSFN environments defined as normal, humid, or harsh; the use of magnesium in a dry environment appears quite feasible.

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* Corrosion resistance is good.
† Corrosion resistance is excellent.

* Refer to table 2-4.
† Licensed process.

PART D. FEDERAL AND MILITARY PAINT SPECIFICATION RESUMES

All performance characteristics in these resumes are based upon proper, adequate surface preparation of the metal and correct application of the proper protective coating. This study advises higher degrees of surface preparation for the various paint systems than current broad coverage paint guides and manuals; it is necessary to achieve the longest possible paint life since the antennas are complex, high-value items and are difficult to schedule for painting.

One difficulty in dealing with federal (TT) and military (MIL) paint specification numbers is finding background data that reveal the characteristics of the coating. These data can be sifted from the TT and MIL specifications for a particular paint; however, obtaining and reviewing one total specification is a lengthy task. To ease this work, the following list contains outstanding characteristics of the TT and MIL specifications used in tables 4-9 through 4-17.

TT-C-530 ——————— Paint, fish oil base: rust inhibiting for use as a spot repair paint, can be used for spot repairs on most types of paint systems
Pigment: bright red iron oxide
Set to touch: 2 hours
Dry: 24 hours
Brushing properties: satisfactory

TT-E-485 ——————— Enamel, alkyd: rust inhibiting for use on cleaned and pretreated metals
Pigment: chrome yellow, red lead and zinc oxide
Performance: good in humid environments, can be used as a one-coat system over cleaned and pretreated metals or a two-coat system using first coat as primer
Dry: air dry or bake
Colors: olive drab, olive green, Marine Corps green, natural, various green colors can be top coated with other colors.
Types:
    Type I   —   phthalic alkyd resin (long-oil soya modified), dip application, set to touch in 3 hours, dry through in 16 hours, hard in 72 hours
    Type II   —   phthalic alkyd resin (long-oil linseed modified), brush and spray, set to touch in 3 hours, dry through in 16 hours, hard in 72 hours
    Type III —   phthalic alkyd resin (medium-oil linseed soya modified), roller coat, set to touch in 3 hours, dry through in 16 hours, hard in 72 hours
    Type IV —   phenol modified alkyd resin, flash dry, set to touch in 10 minutes, dry through in 8 hours, hard in 36 hours

Note

This type of enamel has been used very extensively on military field equipment and much research data has been compiled on it.

TT-E-489 ——————— Enamel, medium oil phthalic alkyd, gloss finish: suitable for use on primed, interior and exterior wood and smooth metal surfaces
Pigment: titanium dioxide*
Performance: good in dry and normal environments, fair performance in humid environments, easy to apply
Colors: 41 colors including white and international orange, international orange† is color number 12197-1
Dry: Class A—air dry, drying time to touch in 2 hours, hard in 8 hours, full hardness in 48 hours

* All TiO$_2$, titantium dioxide, specified for pigmentation for the MSFN facilities shall be rutile chalk-resistant type conforming to type III of federal specification TT-P-442.
† International orange is the bright color used on air navigating obstacles such as water tanks, towers, etc.

Brushing properties: Class A, satisfactory
Spraying properties: Class A, satisfactory when reduced eight volumes of enamel, one volume of thinner
Product should be approved before bids are accepted

TT-E-490 —————— Enamel, silicone, long-oil alkyd, copolymer, semigloss: suitable for use on primed, smooth, exterior, metal surfaces
Pigment: titanium dioxide
Performance: good in most environments, durable; resists yellowing
Colors: 11 and white
Dry: set to touch in 2 hours, dry in 8 hours
Brushing properties: satisfactory
Spraying properties: satisfactory when reduced eight parts enamel to one part thinner

TT-E-522 —————— Enamel, phenolic, lusterless: suitable for use on primed, smooth, exterior,
Formerly metal surfaces
MIL-E-12507 Performance: good in humid environments
Colors: 13 colors and white
Dry: dust free in 30 minutes, dry through in 2 hours, dry hard in 16 hours
Brushing properties: satisfactory
Spraying properties: satisfactory

TT-E-527 —————— Enamel, medium oil alkyd, lusterless: suitable for use on primed, exterior, metal surfaces, air drying or bake drying for equipment use
Performance: good in dry, normal, and humid environments
Colors: 22 and white
Dry: to touch in 2 hours, dry hard in 8 hours
Brushing properties: satisfactory
Spraying properties: satisfactory when reduced four parts enamel to one part thinner
Product should be approved before bids are accepted

TT-E-529 —————— Enamel, alkyd, semigloss: for use on exterior and interior wood and metal surfaces
Performance: good in dry and normal environments
Colors: 36 tints
Dry: Class A—air drying, set to touch in 2 hours, dry hard in 8 hours, full hardness in 72 hours
Brushing properties: satisfactory
Spraying properties: satisfactory

TT-P-38 —————— Aluminum flakes, phenolic resin, ready mixed: suitable for use as top coat on exterior metal surfaces
Performance: good in normal and humid environments
Color: aluminum
Dry: to touch in 2 hours, dry for recoating in 16 hours
Brushing properties: satisfactory
Spraying properties: satisfactory

TT-P-57 —————— Primer, zinc yellow-iron oxide, ready mixed: for use as primer on exterior iron and steel in normal and humid environments
Brushing properties: satisfactory
Spraying properties: satisfactory when five parts primer are reduced with one part mineral spirits
Types:
    Type I — (50/50) raw linseed alkyd vehicle, color is yellow, dry to touch in 4 hours, dry through in 24 hours
    Type II — alkyd vehicle, color is yellow, dry to touch in 2 hours, dry through in 16 hours
    Type III — phenolic varnish vehicle, color is red, dry to touch in 2 hours, dry through in 16 hours

TT-P-59 ——————— Paint, oil alkyd: ready mixed, suitable for top coat on wood and metal surfaces
Performance: suitable in dry and normal environments and for spot repair work in all environments
Color: international orange
Dry: approximately 18 hours
Brushing properties: satisfactory
Spraying properties: satisfactory

TT-P-81 ——————— Paint, alkyd-linseed modified: for use in normal and dry environments and for spot repairs in any environment. Use for repairing alkyd paint systems
Color: white and others
Dry: approximately 18 hours
Brushing properties: satisfactory
Spraying properties: satisfactory

TT-P-86 ——————— Primer, red lead base, ready mixed: for use as primer on exterior iron and steel
Performance: use in dry, normal, humid and harsh environments for spot repair work
Types:
Type I — red lead linseed oil, for use on spot repair work, very good wetting power, dry to touch in 6 hours, dry through in 36 hours, brush and spray properties satisfactory
Type II — red lead mixed pigment, alkyd varnish linseed oil paint, for use in spot repair work on alkyd paint systems, good wetting power, dry to touch in 4 hours, dry through in 16 hours, brush and spray properties satisfactory
Type III — red lead, alkyd varnish paint, for dry and normal environments, dry to touch in 1 hour, dry through in 6 hours, brush and spray properties satisfactory
Type IV — red lead mixed pigment, phenolic varnish paint, for humid environments, dry to touch in 1 hour, dry through in 6 hours, brush and spray properties satisfactory

TT-P-102 ——————— Paint, linseed oil, titanium, lead, zinc pigment: ready mixed
Performance: for spot repair of top coats in all environments
Color: Class A for use as a white paint only, Class B base for use as a tinted paint or a nonchalking white
Dry: 18 hours
Brush properties: satisfactory
Spray properties: satisfactory

TT-P-105 ——————— Paint, linseed oil, zinc oxide, titanium dioxide, chalk resistant, lead free: ready mixed
Performance: for spot repair of top coats in all environments
Colors: White and tints
Dry: 18 hours
Brushing properties: satisfactory

TT-P-615 ——————— Primer, basic lead silicon chromate: ready mixed, for use as primer on iron and steel
Performance: good in dry, normal, and humid environments
Color: yellow
Brushing properties: satisfactory
Spraying properties: satisfactory when using one part mineral spirits to eight parts primer
Types:
Type I — raw linseed-alkyd vehicle (4/1), for dry environments, dry to touch in 6 hours, dry through in 36 hours, for spot repair work in all environments

Type II — raw linseed-alkyd vehicle (1/1), for dry and normal environments, dry to touch in 4 hours, dry through in 16 hours, for spot repair work in all environments

Type III — alkyd varnish paint, for dry and normal environments, dry to touch in 1 hour, dry through in 8 hours

Type IV — phenolic varnish paint, for humid environments, dry to touch in 1 hour, dry through in 6 hours

Type V — raw linseed-alkyd vehicle (2.25/1.0), for dry and normal environments, dry to touch in 6 hours, dry through in 36 hours

TT-P-636 ———————— Primer, alkyd: for wood and ferrous metals
Performance: good in dry and normal environments
Color: red
Dry: air drying or baking, set to touch in 1 hour, dry through in 18 hours, full hardness in 72 hours
Brushing properties: satisfactory
Spraying properties: satisfactory when reduced one part of mineral spirits to five parts paint. Product approval is required before bids are accepted

TT-P-641 ———————— Primer, zinc dust, zinc oxide: ready-to-mix paint, for use on galvanized surfaces
Performance: good on galvanized surfaces
Color: yellow, green, amber tints
Brushing properties: satisfactory
Spraying properties: satisfactory

Types:

Type I — zinc dust, zinc oxide, linseed oil paint, dry to touch in 8 hours, dry hard in 18 hours

Type II — zinc dust, zinc oxide-phthalic alkyd resin paint, dry to touch in 4 hours, dry hard in 18 hours

Type III — zinc dust, zinc oxide phenolic resin paint, dry to touch in 4 hours, dry hard in 18 hours

TT-P-645
(Supersedes
MIL-P-735) ———————— Primer, zinc-chromate alkyd type: for use as an after pickling coating on steel and as a primer for steel and aluminum
Performance: good in dry and normal environments
Color: yellow
Dry: to touch in 1 hour, dry hard in 6 hours

MIL-E-7729 ———————— Enamel, gloss, nonvolatile phthalic anhydride
Performance: good in dry and normal environments
Colors: 16 colors
Dry: set to touch in 30 minutes, dust free in 2 hours, full hardness in 48 hours. *flash point not under 80°F.*
Brushing properties: satisfactory, ~~flash point under 80°F~~
Spraying properties: satisfactory, ~~flash point under 80°F~~
Product approval is required before bids are accepted

MIL-C-8514* ———————— Pretreatment, resin acid polyvinyl butyral/zinc chromate, H_3PO_4 is 15—16 percent, should be thinned up to 1-to-1 to prevent livering and lumping, not intended as a permanent protective coating
Dry: hard in 30 minutes
Brushing properties: satisfactory
Spraying properties: satisfactory

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* Some authorities feel that acid content for use on aluminum and zinc should not exceed 10 percent. Thinning does reduce percentage of acid in the pretreatment

MIL-P-8585 ——————— Primer, alkyd zinc chromate: for use on bare aircraft metal surfaces or on surface with pretreatment coating of MIL-P-15328
Performance: good in dry and normal environments
Color: yellow
Dry: to touch in 30 minutes, dry through in 12 hours
Brushing properties: satisfactory
Spraying properties: satisfactory

MIL-P-14504 ——————— Pretreatment, one package, wash primer, polyvinyl butyral resin: for steel, galvanize, aluminum; should be thinned up to 1-to-1 to prevent livering and lumping, not intended for a permanent protective coating
Performance: good in proper paint systems in all environments, useful to seal clean, bare metal and assist the adhesion of subsequent coat, 10 percent by weight of phosphoric acid
Dry: set to touch in 30 minutes; should be dry before priming
Coating thickness: 0.2 to 0.5 mil maximum
Brushing properties: satisfactory
Spraying properties: satisfactory

MIL-P-15328* ——————— Pretreatment, two-component wash primer, basic zinc chromate-vinyl butyral: for use on all types of clean metal surfaces as pretreatment, not intended for a permanent protective coating, applied immediately on clean metal substrates to prevent oxidation
Performance: good in proper paint systems in all environments, phosphoric acid 15 percent by weight, 8 hour pot life, should be thinned up to 1-to-1 with isopropyl alcohol to prevent livering and lumping when spraying
Coating thickness: 0.2 to 0.5 mil
Dry: hard in 30 minutes in dry environment, should be dry before priming
Brushing properties: good
Spraying properties: good
See SSPC-PT-3-64.

MIL-P-15929 ——————— Primer coating, vinyl, red lead: formula 119 for hot spray, for use with hot spray over pretreatment coating MIL-P-15328
Performance: good in harsh environment
Color: red
Dry: to touch in 15 minutes, dry hard in 30 minutes
Hot spraying properties: satisfactory

MIL-P-15930 ——————— Primer, vinyl-zinc chromate: formula 120 for hot spray
Performance: good in dry, normal, humid, and harsh environments
Color: yellow
Dry: to touch in 15 minutes, dry hard in 30 minutes
Brushing properties: satisfactory
Spraying properties: satisfactory

MIL-E-16738 ——————— Enamel, exterior vinyl alkyd: formula 122-82
Performance: good in humid and harsh environment
Color: white
Dry: to touch in 15 minutes, dry hard in 30 minutes
Brushing properties: satisfactory
Spraying properties: good

MIL-L-18380 ——————— Lacquer, vinylidene resin—known as SARAN or Formula 113/54
Performance: good resistance to water and fuel
Color: white and orange
Brushing properties: difficult to brush properly
Spraying properties: satisfactory
Types:
    Type I —— white, titanium dioxide
    Type II —— orange, molybdate orange

* Refer to footnote on preceding page and note 4, page 4-15.

MIL-C-22750 ——————— Epoxy-polyamide: for exterior and interior use on pretreated or metallic surfaces, two-component finish, cured film has good hardness, adhesion and resistance
Performance: good in harsh environment, formulated for protection of areas exposed to chemicals and solvents
Color: many including insignia white
May be used over pretreatments
Dry: dust free in 1 hour, recoat in 16 hours, dry through in 24 hours
Brushing properties: satisfactory
Spraying properties: satisfactory
Types:
    Type I   —   gloss
    Type II   —   semigloss

MIL-P-23236 ——————— Primer, zinc rich silicate: for steel tanks that hold fuel and salt water ballast, Class III has good performance in harsh environment, Type I for new and complete application, Type II for maintenance,
Classes:
    Class I   —   epoxy
    Class II   —   coal tar, epoxy
    Class III —   silicate, phosphate, or silicone zinc; similar to GSFC-TDS-Paint-1
    Class IV —   urethane
Pretreatment required: none, coating goes directly onto properly cleaned metal surface
Brushing properties: satisfactory
Spraying properties: satisfactory
Product should be approved before bids are accepted.

MIL-P-23281 ———————
(Coast Guard)   Primer: Vinyl, red lead; anticorrosive treatment; can be applied only over wash primer MIL-P-15328*
Dry: set to touch in 15 minutes, dry hard in 30 minutes
Brushing properties: satisfactory
Spraying properties: satisfactory

MIL-P-23377 ——————— Primer, epoxy-polyamide: chemical and solvent resistant, is a two-component epoxy
Dry: to touch in 30 minutes, dry hard in 7 hours
Brushing properties: some difficulties
Spraying properties: primarily for spraying application

MIL-P-26915 ———————
(USAF)   Primer, organic binders—epoxy ester or polyether, zinc dust pigmented. Class IV clean, steel. Type I is air cured. Class A is single component.
Performance: good in humid and harsh environments
Drying: between coats of epoxy ester is 8—16 hours. Complete cure of epoxy (8 days) is required if this primer is top coated with vinyl, for example.
Brushing properties: satisfactory
Spraying properties: satisfactory

MIL-P-38336 ——————— Primer, inorganic, zinc-dust pigmented, self-curing: use for steel surfaces, ready to mix, two-component material; inorganic ethyl silicate binder; specify 86 to 94 percent zinc in dry film; affords a protective coating plus cathodic protection to steel
Performance: good in harsh environment; no pretreatment to be used or cathodic protection will be negated
Dry: dust free in 30 minutes, through in 4 hours
Brushing properties: satisfactory
Spraying properties: satisfactory

* Refer to note 4, page 4-15.

MIL-C-38427 ——————— Top coat: for inorganic zinc primer coated steel
(USAF)   Performance: good in humid and harsh environments
                        Colors: grey, green
                        Types:
                          Type I   — air-dry or solvent-release cure
                          Type II   — one-component moisture curing urethane prepolymers
                          Type III   — two-component catalyzed curing prepolymers
                        Classes:
                          Class I   — urethane base prepolymer
                          Class II   — epoxy base prepolymer
                        Brushing properties: satisfactory
                        Spraying properties: satisfactory

VR-3 ——————————— Vinyl resin paint: one type for primer and top coat, for use on exterior
                        iron and steel, use on bare dry white metal, not to be applied over any type
                        of contamination
                        Performance: good in harsh environment
                        Salt spray resistance: generates no film deterioration after 300 hours
                        Color: white available
                        Dry: for recoating in 3 hours
                        Brushing properties: difficult to brush properly
                        Spraying properties: good with proper techniques
                        VR-3 is not compatible with polyvinyl butyral wash coats, VR-6 is wash
                        primer for VR-3

GSFC-TDS-Paint-1 —— Primer: inorganic zinc silicate, self-curing
(NASA)   Performance: good in humid and harsh environments
                        Pretreatment: none is used, primer goes directly on the properly cleaned
                        metal surface. (Class IV) GSFC-TDS-Paint-1 requirements are very simi-
                        lar to MIL-P-23236 or MIL-P-38336, Dimetcote Nos. 4, 5 and 6 are proprie-
                        tary items

Stainless Steel ——————— Stainless steel paints: use only as top or intermediate coat for steel, use
Paints   galvanized metal for substrate
                        Binders for stainless steel pigments: epoxies, epoxy esters, vinyls, and
                        long-oil alkyds; these binders have good qualities when pigmented with
                        stainless steel
                        Performance: stainless steel paint ages well, surface is similar to brushed
                        stainless, uniform pigment size is critical
                        Corrosion resistance: approximates that of 304 stainless

PART E.   LEVELS OF PAINTING ENDEAVOR FOR MSFN STRUCTURES

There are thousands of paints and as many painting techniques and methods, but only three general levels of painting endeavor are applicable to antennas. These levels are original painting, major repair painting, and spot repair painting.

4.17   ORIGINAL PAINT SYSTEM FOR ANTENNAS

The original painting is the logical time to control the long-run problems of corrosion and expensive repair painting. The antenna's environment should determine surface preparation and the type of paint coatings. Guides to such determinations are illustrated in Chapter IV, Parts B

and C. The most critical item of a long-lived paint system is surface preparation. A mandatory quality-controlled pickling should follow the fabrication, deburring, and deedging of all antenna structural members. Probably the best metal surface obtainable for painting is by proper pickling. At no other time will the opportunity arise again for a complete SSPC Class IV, white-metal surface preparation. Attention to design and Class IV sandblasting to minimize and cleanup areas that are subsequently welded will also increase the useful life of the paint system. The choice of wash primers, primers, intermediate, and top

coats should be selected by using two guidelines: the type of metal to be coated and the working environment of the antenna. The original paint coats can be put on in stages with the primers being applied at the factory and the top coats in the field after the structure is erected, or the total original paint system can be completed following fabrication by the manufacturer at the plant. The latter method will achieve a very good system. Skills, tools, materials, environment, motivation, and quality control are usually better managed at the manufacturer's home base. Application of the proper paint coatings under a controlled environment is ideal. The one disadvantage of applying the complete paint system before antenna erection is the possibility of damage during shipping and erecting. Such damage can be controlled and minimized by proper care in handling, packing, shipping, erecting, inspection, and quality control. The following guidelines will assist the specification writer in achieving the optimum in original paint systems for MSFN antennas:

    a. Following fabrication of the individual structural pieces, all parts must be degreased and pickled to remove all mill scale. All rough edges, sharp edges, and burrs must be ground off. Such areas cannot be sandblasted or painted adequately and, therefore, form ideal points for pitting and concentration cell-type corrosion attack. All shop welding flux and debris must be removed to achieve a white-metal condition.

    b. Each piece of structural material so determined by the design and maintenance engineers should be sandblasted to a clean white-metal finish in a controlled environment of above 50°F and below 50 percent relative humidity without salinity or noticeable industrial contaminants. If the item is pickled, it should be rinsed and dried immediately and then placed in a controlled environment.

    c. As soon as the individual sections are whiteblasted and air cleaned or pickled and rinsed, they should receive (within 1 hour) the first paint coating, as specified, in a controlled environment. In no case should any contaminant touch the white-metal surface. This painting should be executed by craftsmen under close quality control and inspection pertaining to environment, quality of paint, uniformity of application, and specified thickness.

    d. It should be specified that before the individual sections are painted, butt ends and edges to be welded in the field erection must be taped 4 inches beyond the weld

edge to exclude paint. Proper design should keep such field welds to a minimum.

    e. Each succeeding step of the specified paint system should receive the same level of quality control and inspection.

    f. Packaging for shipment should stress the protection of the coating system.

    g. After on-station erection, any coating ruptures and all field-weld areas should be prepared and painted exactly to match the factory applied system. The surface preparation of ruptures and welds should be whiteblast, nothing less. The bare white-metal areas should be airblown and sealed with pretreatment or primer exactly duplicating the factory applied system before any contaminant can degrade the white metal. In dry environments, the pretreatment or primer coat should be applied during the same shift; in harsh environments, the pretreatment or primer should be accomplished immediately after the exposure of the white metal. The patches should consist of exactly the same paints, applied in the same sequence, as the original paint system. This is part of the original paint system and is not considered spot repair painting.

    h. Good specifications do not necessarily guarantee good work; they must be enforced by quality control and follow-through. A Critical Path Network and Schedule which contains each specific step of the painting system permits excellent on-station and remote management and technical control.

    i. The costs of original paint systems vary greatly. The price of a high-quality original paint system applied after antenna erection may be three times the cost of a very high-quality original paint system applied at the manufacturer's plant. In addition, it is physically impossible to attain a high level of quality after the antenna is erected because of inaccessible areas, the uncontrolled environment, and the difficulty of quality control. The key to success for original painting is fourfold: tight specifications, controlled environment, good craftsmanship, and quality control.

4.18 MAJOR REPAIR PAINTING FOR ANTENNAS*

One of the seldom realized features of a paint coating or a total system of coatings is the paint

* See Appendix to Chapter IV for contract specification outline for the major repair painting of an antenna.

is not impenetrable and slowly water vapor and oxygen will reach the metal substrate and corrosion will begin. Spots where the substrate is not clean or paint bonding is poor will permit a breakdown of the coating in short time. On the other hand, where the substrate is clean and bonding/adhesion of the proper paint system is good, vapor penetration resulting in corrosion is greatly retarded. Eventually rust spots, spot repair paints, stains, and yellowing lead to a decision for major repair painting. Major repair painting is by far the most difficult of the three levels of painting endeavor because the crew must work in an uncontrolled, usually harsh environment, against some scheduled time, in many inaccessible areas and contend with corrosion, dirt, spot repair coatings, and mission schedules. Without excellent planning and quality control, the preceding difficulties may render such repair work impossible. The following guidelines will assist the specification writer in achieving a high level of major repair work:

a. A very detailed inspection of the total paint system should be made for blisters, cracks, peeling, lifting, hydrocarbons, corrosion areas, types of corrosion, types of paint films, bonding, and adhesion.

b. Inspections should also be made at random to determine the condition of the metal where the coating system appears sound.

c. The degree of environment control required to aid the work, or for man and equipment protection, should be determined.

d. All protective coating ruptures and spot repaired areas should be whiteblasted, feathered into the paint system, blown with dry air, and sealed with a pretreatment or primer as the system requires within a time limit governed by the environment. In harsh environments, it may be necessary to wash and dry the area for each succeeding paint coat because of the rapid saline contamination.

e. The patching paints should duplicate the paints of the existing system to prevent incompatibility problems. The coating thickness of the repair paints should be controlled to approximate the original paint thickness. The stresses of differential heating because of uneven coat thicknesses may cause new ruptures where the original and repair paints meet.

f. A top coat can be applied to the entire structure after the patches are completed. To apply a top coat, all contaminants such as salt and hydrocarbons must be removed. The entire surface might then be roughened by light brush-off type sandblasting, the sand dust blown clear, and the proper

top coat applied before any new contamination takes place. A good alternative to brush-off sandblasting is to dilute the first coat of paint about 10 percent with the proper solvent. This will give better adhesion to the aged paints. The next coat of paint can be undiluted. The top coat should be the same paint as the previous top coat unless a complete compatibility check of the new paint with the existing is made and complete compatibility is assured.

g. Proper management of repair painting on large antennas is very important because of the limited time and the quality control problems involved. The Critical Path Network and Schedule is a valuable management control tool on such repair work.

4.19 SPOT REPAIR PAINTING FOR ANTENNAS

Between major repair painting efforts, small breaks can occur in the protective coating. These ruptures cannot be ignored; they must be properly repaired as soon as possible by the station personnel.

4.19.1 REQUIREMENTS

Spot repair painting is required any time a break in the protective paint coating 1 centimeter in diameter or length is observed. It is not a good practice to wait for a number of such areas to appear before corrective action is taken.

4.19.2 SURFACE PREPARATION

The surface preparation required for spot repair painting must not place the station personnel on a detailed, time-consuming task or it may be neglected altogether. It is not feasible to set up a large sandblast unit to prepare one or two small accessible spots. On the other hand, if the ruptures are in inaccessible corners or there are a number of them, sandblasting may be the most feasible method. Normally, however, surface preparation for spot repairs will be by hand tools: chipping, brushing, scraping and sanding (SSPC-SP 2-63). Such cleaning must achieve a state of surface preparation known as Class II. Class II is achieved, for example, when all loose and nonadherent rust is removed and adjacent paint cannot be lifted in small sections (5 mm squares) by inserting a knife between paint layers and metal or between paint layers. Refer to paragraph 4.4.2.

4.19.3 PAINTS

Immediately upon achieving a Class II surface, the area should be brush painted with a fish oil, linseed oil or long-oil alkyd primer. (Refer to table 4-17.) Such paints have good wetting power, which is necessary for a Class II surface. If the surface is wet or damp, it should be dried before

being primed. These primers require 24 to 72 hours to dry, depending on the environment. Before applying the next intermediate or top coat, any contamination on the repair paint should be washed off with clean water and dried. At least two top coats should be used. The total repair spot buildup should approximate the thickness of the paint films on the structure. The oil type primers and paints for spot repair can be used over almost any dry paint system; however, these must be removed before a major repair painting effort because they will lift when coated with most modern high-solvent content paints.

4.19.4 TEMPORARY WORK

Spot repair painting must be looked upon as a necessary holding-type action accomplished to control corrosion in very small areas for a limited time. Station personnel must give the proper degree of care to this function or corrosion will get out of hand very quickly. Once a major repair painting of an antenna or facility is accomplished within a harsh environment, spot repair painting must be an "as required" effort on a continual basis if the corrosion is to be controlled and the esthetics maintained.

PART F. THE APPLICATION OF PROTECTIVE COATINGS

The data in Part F is intended for painting supervisors and craftsmen with background experience; the use of this information will not upgrade novices to experienced painters. It is presumed that craftsmen will prepare the surface and apply the protective coatings to the MSFN structures and that these craftsmen will be experienced and understand the normal handling of their equipment. In addition to normal applications, several oddities and special techniques have been included that have been amassed by collective experience which should prove quite useful to experienced painting craftsmen and supervisors.

4.20 THE IMPORTANCE OF GENERICS IN PAINTING

Metal facilities that can be inexpensively repainted at any time do not cause concern over problems arising from eclectic paint sources and the disregard of generics. This is not true of the MSFN antennas which are difficult to schedule and expensive to paint; for antennas the generics of the paint system are extremely important. It is prudent to adhere to one generic family of paints to make up a paint system. Generic differences in a paint system should be checked very carefully when one type paint is applied over another. When a generic variation exists the chances of adhesion and/or rejection problems arising are magnified. For example, when the aged paint system is alkyd, a major paint repair work should be alkyd or alkyd vinyl to maintain the generic line. Likewise, overcoating an aged vinyl system with an alkyd may be a mistake, as it is doubtful whether the bite of the alkyd into the aged vinyl would be sufficient to attain the desired adhesion. When the generic line must be changed in a paint system, the following considerations should be made.

a. Make a compatibility/adhesion check as

detailed in paragraph 4.21.1. If there are no compatibility or adhesion problems, the generic line may be changed as per the testing.

b. If there is a compatibility or adhesion problem the paint manufacturer may have a suitable tie coat which can be used that is acceptable to both new and old paints.

c. When there is no suitable tie coat, all protective coatings must be cleaned to an appropriate class of surface preparation,* and a total new paint system with generic lineage applied.

4.21 COMPATIBILITY AND ADHESION OF PAINTS

There are many combinations of paint coats that result in poor adhesion; such paints may not be compatible. Placing one paint over the other may result in lifting or crinkling or show other manifestations of adhesion problems. Incompatibility is readily seen when, for example, an oil paint is top coated by a paint with a highly volatile solvent. The newer the oil paint the more pronounced the reaction, but even an aged oil base paint will be affected to some degree. It is not necessary to use paints with great differences in their binders to give rise to incompatibilities. For example, a VR-3 vinyl is incompatible with some polyvinyl butyral wash primers.

4.21.1 COMPATIBILITY CHECK

The use of incompatible paints can be quite embarrassing, expensive, and time consuming; therefore, incompatibility should always be a major consideration when placing one paint over another. The following actions should be kept in mind:

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* Class of surface preparation required would depend on environment in which the facility operates. Refer to tables 4-9 through 4-17.

a. Ascertain what type of paint system is already on the structure. This is the aged paint.

b. Study the manufacturer's instructions on both the new and aged paints. The manufacturer's instructions are worthwhile because his paints must be used properly in order to meet the claims he makes for them.

c. Perform a compatibility check by selecting several 4- by 6-inch areas at random, preparing the surface of the test areas, and applying the new paint over the aged paint. Make a series of lift tests with special tape about 4 to 10 days after the new paint is applied. The lift test is made by placing several pieces of test tape (3M) over the test area; cut $\frac{1}{2}$ inch by 4 inch strips through the tape and paint coat; pull off tape and see if paint lifts. Use special tape recommended for this purpose.

d. Make a rapid on-the-spot compatibility check by selecting several 4- by 6-inch areas at random; apply pads saturated with the solvent of the new paint. Hold the pads there from 12 to 15 minutes. If there is no sign of any disturbance to the aged paint 30 minutes after the saturated pads are removed, chances are good that the new paint is compatible with the old.

e. Use a tie coat between incompatible paints; it will solve the problem sometimes. However, there is no paint that can serve as a general tie coat between all paints. The use of tie coats to insulate incompatibility should be undertaken with extreme caution.

f. Increase the adhesion when placing a new vinyl on an old vinyl by increasing the solvent content of the first coat of new paint by 10 percent. This rule is generally true for any paints if the new and aged paints are in the same generic family.

g. Resolve all doubts on paint compatibility before undertaking any MSFN work.

4.21.2 GLOSS PAINTS

It is often desirable to obtain a high-gloss finish for the top coat of paint. High-gloss finishes for primer and intermediate coats are not desirable since a dull or matte finish improves adhesion. Use high-gloss paint for top coat only.

4.21.3 WASH PRIMERS

The polyvinyl butyral wash primer is formulated for use on bare metal. The iron, chromate, phosphoric acid, and vinyl generate an exceptionally good interface and serve as a good base for many primers. The same wash coat may not

be effective when used as a tie coat between two generically unmatched paints because it may not have an effective bite into the aged paint; in addition, the action of the H_3PO_4 on the old paper may be undesirable.

4.21.4 AGED PAINTS

The older a paint becomes the more difficult it is to achieve good adhesion between the old and new paints. It is often possible to add the appropriate thinner to a new paint in about a 1-to-10 ratio to permit it a better bite into the old paint.

4.21.5 HIGH HUMIDITY AND WET SURFACES

Paint manuals often advise not to apply paint if the relative humidity is above 50 percent. Should this rule be followed it would be impossible to paint many of the MSFN tracking station facilities. When the 50 percent humidity rule can't be complied with alternatives must be found:

a. The most ideal situation is a complete control of the environment around the antenna by use of a temporary shelter. Such portable shelters large enough to enshroud a 30-foot antenna are on the market. Complete environmental control is somewhat expensive, and it would mean a 30-day outage for the antenna, but very high quality work could be realized.

b. Ketones have been used as drying agents on metals in damp or wet areas, but due to their high evaporation rate and cooling effect, rapid recondensation could occur on the cooled metal surfaces. Ketones are not soluble in water; their value as an aid to water vaporation is somewhat in doubt. Perhaps for such drying an alcohol which is soluble in water would be preferable.

c. Normally the best way to dry a surface for painting in an area of high humidity is by the use of forced hot air. There is a great advantage in heating the metal surface to dry it, as the hot air tends to preclude recondensation on the metal surface. A planned schedule would be required to keep a heater just far enough in front of the spray gun to achieve the effect desired. Large portable heaters and flexible hoses make such a drying operation feasible today; these heaters are available in sizes up to 500,000 Btu.

d. It is also possible to relax the 50 percent relative humidity restriction. This has been done in many areas by using the following guideline: Painting should not be performed any time the temperature is less than 50°F and/or the dew point is less than 5°F below the metal-surface or am-

bient temperature. This approach should be considered as a last resort for work on the MSFN antennas because 5°F from the dew point is a borderline condition that could change unfavorably in a few minutes.

4.22 COLOR OF PAINTS

There are specialized functions that are performed by the colors of paints. Each function is important and the functions are not necessarily related. For example:

a. An aid to quality control: In a series of paint coats that make up a system it is necessary that the painters and the inspector be able to clearly distinguish each succeeding coat. The color of each coat must vary enough to prove each coat covers the entire structure and meets the requirements. A paint system of white on white is difficult to execute, inspect, and guarantee. A much more reasonable color system would be red on the metal, then grey, then white.

b. An aid to appearance: The paint system plays a primary role in maintaining the appearance of any structure. The MSFN antenna colors are white which means dirt and stains are shown more readily than on tinted colors.

c. An aid to thermal distortion problems: The antenna is sensitive enough that differential heating can, if not controlled, cause distortion problems. Since white reflects more heat energy than darker colors, its use minimizes distortion.

4.23 REPAINTING AGED PAINT SYSTEMS

The decision to paint over aged coatings or remove them and begin anew from the metal substrate should not be made until after a careful investigation of the surface of the topmost coat, the adhesion between each coat, and the bonding of the primer to the metallic substrate. Should the bonding be poor, should general corrosion activity be found on the metal substrate, or should the adhesion of any paint coat in the system be poor, then painting over such a weak paint system is unsound in both economic and engineering terms. An aged paint system should have good bonding to the substrate and good adhesion between each coat of paint or it is not worth top coating.

4.24 SOLVENTS

There are many solvents that will dissolve and carry away oils and greases. Solvents are important to surface cleaning because many mineral oils such as hydraulic fluids are highly resistant

to cleaning alkalis and acids. Materials used as effective solvents for cleaning structural steel are naphtha, toluene, turpentine, xylene, Stoddard solvent, and mineral spirits. All solvents are dangerous because of their low flash points and/or toxic fumes. Benzene and gasoline are very volatile and flammable; carbon tetrachloride is toxic. Therefore, they are not recommended for cleaning MSFN facilities. When the existing paint system is to be solvent cleaned and repainted, much care is required to assure that the aged paint system is not weakened or destroyed by the solvent in the cleaning process.

4.25 SPRAYING PAINT

4.25.1 SPRAY TEST PATTERNS

The uniformity of a paint coat sprayed on any type of good substrate shows, to a great extent, the proficiency of the craftsman. It is also attributable to the condition of the equipment, especially the spray gun. (The spray gun is discussed later.) Finally, the paint itself has much to do with the uniformity of the sprayed coating. The viscosity, the temperature, the binder, and other characteristics of the paint will have an impact on coating uniformity. For example, a wash primer such as MIL-P-15328 should be diluted up to a 1-to-1 ratio with the proper thinner. This is also true of the VR-3 vinyls. In general, manufacturers advise certain thinning of their paints when spraying to avoid livering and lumping; however, due to numerous variables that cause nonuniform spray patterns, several test exercises are recommended. The test spray can be made on white or black art paper size 8 inches by 11 inches. One pass with the spray gun is enough; it shows pattern only, not adhesion. The test sprays should be dried and filed for record with all pertinent data noted: time, date, weather, type of paint, name of craftsman, and area of work. Such tests should be made just before starting in the morning and once at random during the day. During the course of a painting program, three or four metal plates should be coated at random times for test and record purposes. Writing such "random sample" requirements into a contract for painting alerts the paint contractor that close inspection will be maintained.

4.25.2 SPRAY PAINTING PROBLEMS

There are numerous single and combination problems that can arise in spray painting. The respected Steel Structures Painting Council investigated and documented many of the problems and possible causes, and then suggested remedies. Refer to table 4-18 for spray painting faults.*

* Steel Structures Paint Council
  Carnegie-Mellon University
  Pittsburgh, Pa.

Table 4-18. Spray Painting Faults and How to Remedy Them

Trouble	Possible Causes	Suggested Remedies
SAGS	1. Dirty air cap and fluid tip (distorted spray pattern). 2. Gun stroked too close to the surface. 3. Trigger not released at end of stroke (when stroke does not go beyond object). 4. Gun stroked at wrong angle to surface. 5. Paint too cold. 6. Paint piled on too heavy. 7. Paint thinned out too much.	1. Remove air cap and clean tip and air cap carefully. 2. Stroke the gun 6 to 10 in. from surface. 3. Operator should release the trigger after every stroke. 4. Gun should be stroked at right angles to surface. 5. Heat paint in an approved paint heater. 6. Learn to calculate depth of wet film of paint. 7. Add the correct amount of solvent by measure.
STREAKS	1. Dirty air cap and fluid tip (distorted spray pattern). 2. Insufficient or incorrect overlapping of strokes. 3. Gun stroked too rapidly ("dusting" of the paint). 4. Gun stroked at wrong angle to surface. 5. Stroking too far from surface. 6. Too much air pressure. 7. Split spray. 8. Paint too cold.	1. Remove air cap and clean tip and air cap carefully. 2. Follow the previous stroke accurately. Deposit a wet coat. 3. Avoid "whipping." Take deliberate slow stroke. 4. Gun should be stroked at right angles to surface. 5. Stroke 6 to 10 in. from surface. 6. Use least air pressure necessary. 7. Clean the fluid tip and air cap. 8. Heat paint to get good flow out.
"ORANGE-PEEL"	1. Paint not thinned out sufficiently. 2. Paint too cold. 3. Not depositing a wet coat. 4. Gun stroked too rapidly ("dusting" the paint). 5. Insufficient air pressure. 6. Using wrong air cap or fluid nozzle. 7. Gun stroked too far from the surface. 8. Overspray striking a previously sprayed surface.	1. Add the correct amount of solvent by measure. 2. Heat paint to get good flow out. 3. Check solvent. Use correct speed and overlap of stroke. 4. Avoid "whipping." Take deliberate slow strokes. 5. Increase air pressure or reduce fluid pressure. 6. Select correct air cap and nozzle for the material and feed. 7. Stroke the gun 6 to 10 in. from surface. 8. Spray detail parts first. End with a wet coat.
EXCESSIVE PAINT LOSS	1. Not "triggering" the gun at each stroke. 2. Stroking at wrong angle to surface. 3. Stroking gun too far from the surface. 4. Wrong air cap or fluid tip. 5. Depositing a paint film of irregular thickness. 6. Air pressure too high. 7. Fluid pressure too high. 8. Paint too cold.	1. It should be a habit to release trigger after every stroke. 2. Gun should be stroked at right angles to surface. 3. Stroke the gun 6 to 10 in. from the surface. 4. Ascertain and use correct setup. 5. Learn to calculate the depth of wet film of finish. 6. Use the least amount of air necessary. 7. Reduce pressure. If pressure keeps climbing clean regulator on pressure tank. 8. Heat paint to reduce air pressure.
EXCESSIVE SPRAY FOG	1. Too high air pressure. 2. Spraying past surface of the product. 3. Wrong air cap or fluid tip. 4. Gun stroked too far from the surface. 5. Material thinned out too much.	1. Use least amount of compressed air necessary. 2. Release trigger when gun passes target. 3. Ascertain and use correct setup. 4. Stroke the gun 6 to 10 in. from surface. 5. Add the correct amount of solvent by measure.
PAINT WON'T COME FROM SPRAY GUN	1. Out of paint (gun begins to sputter). 2. Settled, caked pigment blocking gun tip. 3. Grit, dirt, paint skins, etc., blocking gun tip, fluid valve, or strainer.	1. Add paint, correctly thinned out and strained. 2. Remove obstruction; stir paint thoroughly. 3. Clean your spray gun thoroughly, and strain the paint. Always strain paint before using it.
PAINT WON'T COME FROM PRESSURE TANK	1. Lack of proper air pressure in the pressure tank. 2. Air intake opening, inside of pressure tank lid, clogged by dried-up paint. 3. Leaking gaskets on tank cover.	1. Check for leaks or lack of air entry. 2. This is a common trouble. Clean the opening periodically. 3. Replace with a new gasket.
PAINT WON'T COME FROM SUCTION CUP	1. Dirty fluid tip and air cap. 2. Clogged air vent on cup cover. 3. You may be using the wrong air cap. 4. Leaky connections on fluid tube or nozzle.	1. Remove air cap and clean tip and air cap carefully. 2. Remove the obstruction. 3. Ascertain and use correct setup. 4. Check for leaks under water, and repair.
GUN SPUTTERS CONSTANTLY	1. Fluid nozzle not tightened to spray gun. 2. Leaky connection on fluid tube or needle packing (suction gun). 3. Fluid pipe not tightened to the pressure tank lid.	1. Tighten securely, using a good gasket. 2. Tighten connections; lubricate packing. 3. Tighten. Check for defective threads.
PAINT LEAKS FROM SPRAY GUN	1. Fluid needle packing nut too tight. 2. Packing for fluid needle dry. 3. Foreign particle blocks fluid tip. 4. Damaged fluid tip or needle.	1. Loosen nut, lubricate packing. 2. Lubricate this part daily. 3. Remove tip and clean. 4. Replace both tip and needle.

APPENDIX

SAMPLE SPECIFICATION

Date_____

_____

(name of firm)

Specification #_____

Surface Preparation and Corrosion Control/Painting of the
USB Antenna at the_____Tracking Station.

1. SCOPE

The work to be done under these specifications consists of the surface preparation and paint applications required to establish a protective coating on the Apollo USB antenna at the .... Tracking Station which is located at ....

The work shall be complete; it shall include all labor, material, equipment, tools, supplies, services and performance of all operations necessary for, or incidental to, the corrosion control repair painting as specified here. The entire structure, including, but not limited to, the X-Y axis structure, the dish backup structure, the parabolic reflector panels, the quadruped, the hydromechanical building, and the air-conditioning equipment for the antenna lies within the scope of work.

2. DESCRIPTION

2.1 SURFACE PREPARATION

The contractor shall clean the surfaces of the antenna structure and remove all products of grease, dirt, corrosion, loose paint, etc., as specified.

2.2 REPAIR COATINGS

Following surface preparation, the contractor shall apply a surface pretreatment, prime coat, and finish coat to all exposed whiteblasted areas as specified.

2.3 NEW COATINGS

The entire antenna structure shall be surface coated as specified herein, subsequent to the paint repair work.

2.4 TECHNICAL DATA AND REFERENCES

This specification defines the surface preparation and materials involved. Application techniques may be chosen by the contractor if they are based on acceptable and proven techniques for structural steel painting and if they are approved by the contracting officer or his authorized representative.

2.5 SPECIAL CONSIDERATIONS

There are circumstances that the contractor must understand to execute the contract in a proper manner: travel to a remote or security area; possible interruption of the work schedule because of an unexpected mission levy; the complexity of the dish backup structure and X-Y axis structure. In addition, certain features of the antenna are extremely sensitive. The contractor will be instructed on protective procedures regarding these sensitive areas as required.

2.6 TOTAL WORK

This is a total effort for the total antenna structure wherein the protective coating systems shall be upgraded to achieve a uniform, highly corrosion-resistant system.

3. COMMENCEMENT, PROSECUTION, AND COMPLETION OF WORK

The contractor shall be required to complete all work during the period specified. Unscheduled periods of interruption of the contractor's work to allow the use of the antenna to support missions may occur. In the contractor's bid quotation, he must quote a cost per day when his work is suspended due to nonavailability of the antenna because of an unscheduled mission. The work time allowable will be increased by the amount of time consumed in unscheduled missions. The Critical Path Schedule and Network attached to these specifications lists the time segments for different parts of the work.

4. OCCUPANCY OF PREMISES

The contractor shall arrange with the contracting officer or his authorized representative for security procedures, means of access to premises, and space for storage of materials and equipment, etc., before the work is started.

The interiors of all structures and outside areas except as designated, are off limits to all contractor personnel. The contracting officer or his authorized representative will consider requests for access to off-limit areas on an individual basis.

5. STATION INVESTIGATION

A station investigation by the contractor prior to the start of work is mandatory. He must understand the nature of the work involved, the antenna configuration, the rigging required, safety requirements, tools and equipment necessary, the impact of mission schedules, the environment, etc.

6. RESPONSIBILITY

Technical guidance, inspection, and acceptance of the work will be by the contracting officer's representative.

Work supervision is the responsibility of the contractor. The contractor must check and ensure the fulfillment of all technical requirements such as dependable equipment, craftsmanship, materials, subcontractor services, and safety.

7. SAFETY MEASURES

Moving machinery, electrical lines, high places, slippery walkways, etc., require safety precau-

tions. The contractor will submit a proposed safety plan to the contracting officer or his authorized representative for approval prior to commencing work. Protective goggles, eye-wash kits, safety lines, hard hats, and proper foot-gear are to be provided by the contractor. The approved safety plan shall become a part of this contract.*

8. UTILITIES

The station will provide electrical power and water. The contractor will provide the electrical transmission wiring necessary to power his equipment, etc. Lavatory facilities must be provided by the contractor. The contractor will provide all utility materials, equipment, tools, labor, utility lines, and services except as noted above.

9. STANDARDS AND SPECIFICATIONS

The latest issue, at the date of invitation to bid, of the following standards and specifications shall apply to the work required. In case of conflict between these specifications and the specifications listed below, the requirements of these specifications shall govern:

a. MIL-STD-171—Surface Preparation
b. MIL-T-704—Treatment and Painting of Material
c. TT-C-490—Cleaning Methods and Pre-treatment
d. SSPC-SP7-63 — SSPC-SP6-63, SSPC-SP 10-63, SSPC-SP5-63—the four classes of Surface Preparation
e. MIL-P-15328 — Formula 117, Pretreatment Primer
f. MIL-P-8585—Primer, Zinc Chromate
g. TT-E-489—Enamel, Alkyd, Gloss

10. SPECIFIC REQUIREMENTS

10.1 EQUIPMENT

The following are requirements on equipment:

a. The contractor shall include the use of a cherry picker (high lift) in his bid.
b. The steam-cleaning equipment must be rated at 100 pounds per square inch or higher discharge pressure.
c. The sandblast units must have compressors sized 100 pounds per square inch and 125 cubic feet per minute or larger. The sand-blast nozzles must be 1/8-inch venturi types.

* See publication Z2 1959 of the American Standards Association: *Protection of Head, Eyes and Respiratory Organs.*

10.2 SURFACE PREPARATION DETAILS

10.2.1 MASKING

All openings where water, steam, detergent, or sand can penetrate and result in electrical or mechanical trouble must be carefully masked before the work starts. Such openings will be designated by station personnel. Items not to be painted must also be masked.

10.2.2 DEGREASING

Hydraulic oils and greases may require removal by solvent. Solvent use must be approved by the contracting officer or his authorized representative.

10.2.3 STEAM CLEANING

All water-soluble dirt and all oil and grease must be removed to the extent there is none visible to the naked eye or sensible to the touch. This process may require steam cleaning with saturated steam carrying some type of soap or detergent which must be rinsed off completely after the cleaning. A detergent with a pH value of 7.0 must be used unless the contracting officer approves another.

The aluminum reflector panel will be steam cleaned with maximum care. A test section of the back of a panel will be cleaned to determine the method to be used. Once the steaming is completed for the entire antenna, it will be thoroughly and completely rinsed with hot clean water. This rinsing must be so complete that any part of the structure will pass a litmus paper alkali test. It is recognized that some paint may be removed in this cleaning process.

10.2.4 WHITEBLAST

Whiteblast will be used where required because of protective-coating weather peeling, chipping, corroding, scaling, and general deterioration. Whiteblast is defined in SSPC-SP5-63. All sand and dust must be blown free before painting.

10.2.5 REFLECTOR PANELS

The reflector panels will not be sandblasted nor will they be subjected to an errant blast of sand. (The reflector panels will not be removed.) They may be cleaned with a 25 psi steam spray with detergent as specified in paragraph 10.2.3.

10.2.6 ANTENNA STRUCTURE

Subsequent to the sandblasting and previous to painting, each particular structural part will be airblown completely with compressed air to remove all loose sand and contaminants.

10.2.7 REFLECTOR PANEL BACKUP STRUCTURE

This is the steel gridwork that forms the support for the aluminum reflector panels, the parabolic dish. This structure terminates at the Y-axis wheelhouse level. The dirt accumulation on this gridwork varies from very light to medium heavy and can be cleaned with unadulterated saturated steam or hot water spray (25 psi minimum). In cases of stubborn contaminants a detergent with a pH of 7.0 (neutral) may be used. This must be followed as soon as possible by a very thorough rinsing to remove all traces of detergent. Approximately .... percent of the total reflector panel backup structure has been chipped, abraded, etc., and must be cleaned to white metal. Sandblasting can be used to achieve the required white-metal condition on the ruptured coating areas; however, maximum care must be taken to protect the reflector panels because all the cleaning necessary to the backup structure must be accomplished while the reflector panels are in place.

10.2.8 X-Y AXIS STRUCTURE

The total X-Y axis structure must be cleaned with high pressure (100—150 psi) steam carrying a proper cleaning agent, preferably with a pH of 7.0 The structure sections that are stained with highly viscous and adhesive oil will present the most difficult cleaning problem; however, a dirt and oil free surface must be achieved. After the steam and cleaning agent are used, the residue of the cleaning agent must be removed with hot water. If a detergent other than one with a pH of 7.0 is used then random and numerous litmus paper tests must be made to assure the effectiveness of the rinse. Approximately .... percent of the X-Y axis structure must be whiteblasted because of corrosion, abrasion, and coating system ruptures.

10.2.9 SURFACE COATING PREPARATION

Each structural part or component will be cleaned, rinsed, and sandblasted as specified prior to surface coating. The antenna will be surface coated as specified herein.

10.3 COATING SYSTEM DETAILS

10.3.1 SCHEDULING

Whiteblasted areas must not be permitted to become contaminated or corroded before the initial pretreatment or primer coat is applied. To avoid surface corrosion, whiteblast areas must be sealed within 8 hours after blasting if the relative humidity does not exceed 25 percent. If the relative humidity exceeds 25 percent, the whiteblast areas must be sealed in less than 8 hours after blasting to avoid surface corrosion. The contractor will not permit any prepared surface to become contaminated or corroded in any manner whatsoever before applying the next paint coat.

10.3.2 COMPATIBILITY OF PAINTS

It is mandatory that the binders, solvents, and pigments of the patch system (repair work) paints be compatible with the paints of the system being patched. Incompatible paints may not cure properly and may curl, flake, crack, blister, or not endure.

10.3.3 CURING TIMES

Each paint coat will be allowed proper curing time as specified in the manufacturer's instructions.

10.3.4 CONTAMINATION

Contamination by any gaseous, liquid, solid, or combination of substances that impairs the bonding of paint to metal or adhesion of paint to paint must be prevented. (See scheduling.)

10.3.5 TEMPERATURE

The temperature ranges allowable during application and curing stated by the paint manufacturer will be followed.

10.3.6 PAINTS

10.3.6.1 PRETREATMENT. Areas to be painted must be clean. All whiteblast areas will receive a 0.3 to 0.5 mil coat of Formula 117, MIL-P-15328. It must be applied as a base for MIL-P-8585. Formula 117 is stable for a maximum of 6 hours of pot life in very dry air.

10.3.6.2 PRIMER. The existing primer for the entire structure is zinc chromate. The primer must conform to MIL-P-8585 and be from a qualified products list or be subject to independent laboratory analysis or the submission of a certificate of compliance at the contractor's expense. The primer will be applied by brush or gun so as to dry 2 mils in thickness. Curing time is 12 to 24 hours.

10.3.6.3 TOP COAT. The existing top coat of the X-Y axis structure is enamel, white alkyd, gloss; TT-E-489. The top coat used for the repair work will conform to TT-E-489 and will be a qualified product or subject to independent laboratory tests or the submission of a certificate of compliance at the contractor's expense. The enamel will be applied to the total area as to dry 2 mils in thickness. Proper brush or spray application is acceptable.

10.3.6.4 CLEAN UP. At no time during the work will the contractor permit a dangerous or unsightly accumulation of trash or materials at

the station. Immediately following completion of the work, the contractor will remove all of his material, tools, equipment, trash, and personnel from the station area. The contractor will leave the grounds, etc., around and in the vicinity of the station in an "as found" condition.

11. MANAGEMENT CONTROL

Because of the critical time element involved, the contractor must use a Critical Path Schedule and Network to program the work. The contractor has three options prior to contract award regarding the Critical Path Method (CPM) Network and Schedule:

    a. He may accept the proposed CPM Network and Schedule. (See figure 4-1.)

    b. He may request changes in any of the work segment duration times provided such

changes do not lengthen the time to completion as designated.

    c. He may calculate his own Critical Path Method Network and Schedule. It must not exceed the total time specified and is subject to approval of the contracting officer or his representative.

12. QUALITY CONTROL

The technical representative of the contracting officer will monitor the entire work prescribed herein. The technical representative will make all tests such as dust, litmus, adhesion, thickness, color, etc., deemed necessary to assure good work. At least six test panels will be painted at random times during the work. These panels will be filed for any subsequent evaluation.

CHAPTER V. SURFACE TREATMENTS FOR CORROSION CONTROL

INTRODUCTION

5.1 GENERAL

In addition to paint coatings, there are many surface treatments that will protect structural metals from corroding. Such treatments include electroplating, anodizing, metallizing, hot dipping, and cladding. Each surface treatment imparts special properties which are desirable for architectural finishes or for corrosion control. The effort to control corrosion is the primary reason for the surface treatment of metals. The selection of the proper surface treatment for a metal or alloy for any of the MSFN tracking station facilities should be made subsequent to a study of all the factors involved. The difficulty does not lie in eliminating the unsuitable processes; it lies in the selection of the best surface treatment from the ones that appear to be capable of good performance. Final selection should be made only after studying the environment and the functional role of the metal. Chapter V reviews the highlights of many surface treat-

ments. The use of zinc coatings for corrosion protection and the metal flame-spray process are detailed separately in Chapter V, Part B, because of their widespread use and corrosion-control potential.

5.2 TECHNICAL

The selection of surface treatments is largely the responsibility of the design engineer; however, some of the most valuable advice the designer receives comes from the field engineer. This chapter will assist the field engineer to make reports on the performance of surface treatments which will receive attention. Better communications between the design and maintenance engineers is a worthwhile goal, with economic and performance gains as the prizes. Chapter V also details the flame-spraying (metallizing) process, an effective metallic surface treatment which the field engineer can utilize.

PART A.   TECHNIQUES IN GENERAL

The effects of corrosion would increase the operational costs of many low-alloy metallic facilities to levels which could not be reasonably estimated if it were not for the protective coatings of paints detailed in Chapter IV and the other protective coatings applied to base metals by hot dipping, electroplating, anodizing, chromizing, sherardizing, bonderizing, flame spraying, and metal cladding. All such surface treatment processes are detailed by the concerned industries and by military specifications. However, it is pertinent to this study that the highlights of each technique be given for the purpose of quick review and comparison. The techniques and properties of such surface treatments excluding paint coatings follow.

5.3   CHEMICAL COATINGS

This process involves chemical reaction with the metal on which the coating is formed. Several methods can be used.

5.3.1   ANODIZING

An anodic coating on aluminum consists of a layer of aluminum oxide approximately 0.0005 inch thick. The coat is formed when the metal to be coated is made the anode in an acid electrolyte. Electrolytes commonly used are sulfuric acid or chromic acid. The coat is approximately 1000 times thicker than the natural oxide film and, therefore, greatly improves resistance to abrasion and corrosion. Anodizing may be considered as the opposite of electroplating because porous-type anodic coatings start on the surface of the metal and progress inward. The last formed coating is at the base metal-coating interface, and the first formed portion of coating is on the surface. Aluminum anodic coatings consist of fine, hollow, hexagonal-shaped cells of aluminum oxide. The star-shaped cavities penetrate much of the coating thickness, but they do not pass completely through the anodic film to the base metal. The size of the cavity varies from electrolyte to electrolyte, and

the cell wall thickness depends primarily on the process voltage employed. Anodic coatings sealed in boiling water convert some of the oxide of the cell wall to a hydrated form. The hydrate possesses a larger volume than the consumed oxide and thus seals or plugs the cells or pores and prevents the entry of foreign substances into the coating.

The present state-of-the-art practice is to dissolve chromium salts in the water used to hydrate the oxide. These compounds, sealed in the film, act as residual corrosion inhibitors. For other uses, particularly in the architectural field, these same porous coating characteristics allow the production of colored anodized parts. Dyes are sealed into the anodized coating and, combined with the excellent abrasion resistance of anodic films, provide corrosion-resistant, permanently-colored surfaces for aluminum. For details of anodizing, see figure 3-1 and refer to MIL-A-8625; type I is for chromic acid, type II is for sulfuric acid, and type III is for hard anodic coatings. Also refer to MIL-C-60539 for conventional coatings and MIL-C-60546 for hard coatings. For chemical finishes for aluminum, refer to MIL-C-5541.

5.3.2 CHROMATE COATINGS

These coatings are used on magnesium alloys and to a lesser extent on zinc. The chromate coatings are produced in thin films by several processes. The simplest method is to dip the metal in a chromate solution. The coating gives some mechanical protection and provides some control over electromechanical corrosion because the anodic activity is decreased by the chromate action. For details of chromate coating, refer to MIL-S-46055 for chromizing steel, MIL-C-11463 for chromium (gray-plated), and MIL-C-17711 for chromatizing zinc alloy castings and hot-dipped galvanized surfaces.

5.3.3 PHOSPHATE COATINGS

The application of phosphate coatings, known as parkerizing and bonderizing, is accomplished by dipping the steel surfaces into the proper iron phosphate and manganese solution. For details pertaining to parkerizing and bonderizing, refer to MIL-P-12232. For phosphate coatings on steels, refer to TT-C-490; type I is for zinc phosphate, type II for iron phosphate, and type III for organic pretreatment coating.

5.3.4 GRANODIZING

In the process of granodizing, the base metal is made the cathode in a hot solution of zinc phosphate and phosphoric acid. A dense, black coating can be produced on iron, zinc, and cadmium which is resistant to weathering.

5.4 METALLIC COATINGS

Metallic coatings for protecting underlying metals perform one or possibly two functions regarding corrosion control. One function that is always evident is isolation of the structural metal from an environment that is attempting to corrode it. The second function depends upon the positions of the structural metal and coating metal in the electromotive series. Zinc, aluminum, and cadmium coatings will give galvanic protection to steel. Tin, nickel, and chromium, which are more noble than steel, do not protect the steel cathodically. There are many metallic coatings and many means of application.

5.4.1 ELECTROPLATING

Electroplating metals from aqueous solutions is an excellent method to protect alloy steel components from their environment. A variety of metals including gold, silver, copper, chrome, nickel, cadmium, zinc, lead, and tin can be plated on ferrous metal substrates. One structural metal that cannot be readily electroplated by protective metals is aluminum. Electroplating has many advantages: ease of application, high adhesion, good continuity, and long service life. A major difficulty is its effect on mechanical properties of plated metal. In strength levels of approximately 200,000 pounds per square inch, embrittlement, resulting from hydrogen absorbed by the steel during plating, becomes critical; hydrogen is liberated in the deposition process by electrolysis of water at the cathode. Two methods for circumventing this problem are plating by mechanical means and electrodeposition of metal from nonaqueous solutions (fused salts). Several military specifications cover electroplating. Refer to QQ-Z-325 and QQ-S-775 for zinc, QQ-P-416 for cadmium, and QQ-N-290 for nickel.

5.4.2 HOT DIPPING

Hot dipping is immersing the metal to be protected in a molten cover metal. Galvanized steel is usually produced by dipping a clean sheet of metal in a molten bath of zinc. Dip time is about 3 minutes; a thinner coating of zinc can be placed on metals by electroplating. Refer to Chapter V, Part B and QQ-S-775 for additional galvanizing data. For hot dipping aluminum, refer to MIL-A-40147 and MIL-S-4174.

5.4.3 DIFFUSION COATINGS

Diffusion in solids is very slow, but is a well recognized phenomenon. Physical metallurgy is vitally concerned with the diffusion phenomenon. This phenomenon includes the partial fusion of metal powders, the movement of metal ions through oxides, the passage of metals in alloys

through the lattices of atoms, and the movement over the surface grain and along the grain boundaries. Metallurigsts have used this natural tendency of solid diffusion to put protective metal surfaces on iron or steel. The diffusion coatings impart various characteristics to the base metal, including heat resistance and corrosion resistance. The diffusion coatings can also provide bearing surfaces.

5.4.3.1 CALORIZING.

This is one of the earliest commercial processes developed for the aluminum coating of steel. The basis of the calorizing process is the formation of a surface iron-aluminum alloy by diffusion and an intimate contact of the base metal and aluminum at an elevated temperature. The surface preparation required is whiteblast (SSPC-SP5-63); the parts are packed with a calorizing power into a gas-tight retort which is heated from 1550 to 1700°F for several hours. Calorizing powders vary widely; a typical mixture is 49 percent aluminum powder, 49 percent alumina, and 2 percent ammonium chloride. The alumina keeps the metallic aluminum grains from fusing together. The aluminum-iron surface alloy formed varies from 0.001 to 0.006 inch thick depending on the original composition of the steel. The calorized metal is highly resistant to oxidation and corrosion at elevated temperatures. Calorized steels are difficult to fabricate.

5.4.3.2 CHROMIZING.

This process forms a chromium-iron surface alloy by diffusion. It results from the intimate contact of the base metal and chromium at an elevated temperature in a gas-tight retort. Except for the powder composition, chromizing is a process similar to calorizing.

5.4.3.3 SHERARDIZING.

This process forms a zinc-iron surface alloy by diffusion. The Zn-Fe surface alloy is a result of the high temperature and intimate contact of the zinc powder and iron.

Except for the powder composition, sherardizing is a process similar to calorizing.

5.4.3.4 IHRIGIZING.

This process forms a ferrosilicon-iron surface alloy by diffusion. Except for the powder composition, ihrigizing is a process similar to calorizing.

5.4.4 METALLIZING (FLAME SPRAY)

Metal flame spray is a versatile operation for both field and factory use. Metal wire or powder is melted, atomized, and driven onto a prepared substrate by a special flame gun using compressed air. The metal particles solidify in the air; therefore, the bond to the substrate is mechanical. The coating is porous and when sealed is very good for corrosion protection. See Chapter V, Part C, MIL-M-6874 and MIL-M-3800 for additional data on metallizing.

5.4.5 METAL CLADDING

Cladding is the metallurgical binding together of two different metals to acquire special surface properties such as corrosion or heat resistance. The desired topping or cladding metal is bonded to the base metal by heating and rolling. Cladding can also be achieved by casting to surround the base metal or building the surface by welding the desired clad metal on the base metal. In producing corrosion-resistant sheet or plate, mild steel plate can be clad with stainless steel. Pure nickel or a nickel chromium alloy is often bonded to steel for corrosion-resistant purposes. The alclad series of aluminum alloys consists of an aluminum alloy core with a surface of pure aluminum or a highly corrosion-resistant aluminum alloy. Certain magnesium alloys are also clad with magnesium for the same reason—corrosion resistance. For additional details, refer to QQ-S-682; for the metal cladding of steel, refer to QQ-A-250/13, Alclad, QQ-A-250/15, Alclad, and QQ-A-250/18, Alclad.

PART B.   PROTECTIVE COATINGS OF ZINC

Of all common metals used for protective coatings, zinc has the lowest cost per pound. Zinc coatings are applied by various methods: hot dipping, electroplating, flame spraying, sherardizing, cementation, and vapor deposition. Of these, hot dipping and electroplating are predominant. Zinc makes a very tough, long-lasting, economical coating for steel, and its primary advantage is its ability to protect steel from corroding, both as a barrier and cathodically.

5.5   HOT-DIP GALVANIZING

Hot-dipped galvanized steel was first produced in 1837, and zinc coatings have been used to protect many ferrous products since then. Galvanized, the name given to zinc-coated steel, was coined because of the "galvanic" protection from corrosion enjoyed by steel when it is in contact with zinc.

The hot-dip galvanizing process begins with a thorough cleaning to remove all oils, greases, and contaminants from the metal surface. The clean-

ing cycle is continued with a pickling phase to remove scale, corrosion products, etc. Following the cleaning cycle, the metal is treated in zinc-ammonium chloride and dried. Finally, the cleaned and fluxed base metal is submerged or dipped in a molten zinc bath which varies in temperature between 820 and 880° F, depending on the processing of the metal.* The zinc bath is not pure zinc because small amounts of aluminum, cadmium, and tin are used in the alloy to produce special finishes. Zinc coatings placed on steel by the hot-dip process are, in effect, several layers. There is one very thin layer of $FeZn_3$ next to the steel, a second of the iron-zinc alloy $FeZn_7$, and finally, the top layer of zinc, which has approximately the same composition as the molten zinc in the galvanizing bath. Figure 5-1 shows a 500-diameter magnification of the hot-dip zinc and steel substrate junction line.

The zinc-coating weight varies from very light on some sheets to extremely heavy on hand-dipped

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* At temperatures below 820°F, the quality of the zinc coating falls below normal; above 880°F, the heat degrades the quality of the finish.

items. The coating thicknesses range from thin coats of 0.0002 inch for light containers through 0.002 inch for some utility pipes to 0.004 inch on heavy metal. The quantity of zinc on a galvanized sheet is given in terms of ounces per square foot of sheet. Because the sheet is coated on both sides, the given weight of the zinc coating is twice the average weight of coating per square foot of either side. A zinc weight of 1.25 ounces per square foot is approximately one mil (0.001 inch) of zinc on each side. Zinc-coating weights applied to sheets by the hot-dip process range from 0.6 to 2.5 ounces per square foot. The common 1.25 ounces per square foot commercial coating class generally includes those that are produced on sheets for direct weather exposure. For additional details on hot-dip galvanizing of steel, see QQ-S-775.

5.6 ELECTROGALVANIZING

Electroplating uses an electrical current in an electrolytic cell arrangement to deposit zinc on the steel. It has also been called a cold or wet galvanizing process to classify it as a separate process and not a form of hot dipping. The baths of the electro-

AIR

ZINC OF BATH COMPOSITION (ETA)

$FeZn_{13}$ (ZETA)

$FeZn_7$ (DELTA PRIME)

$FeZn_5$ (GAMMA)

STEEL SUBSTRATE
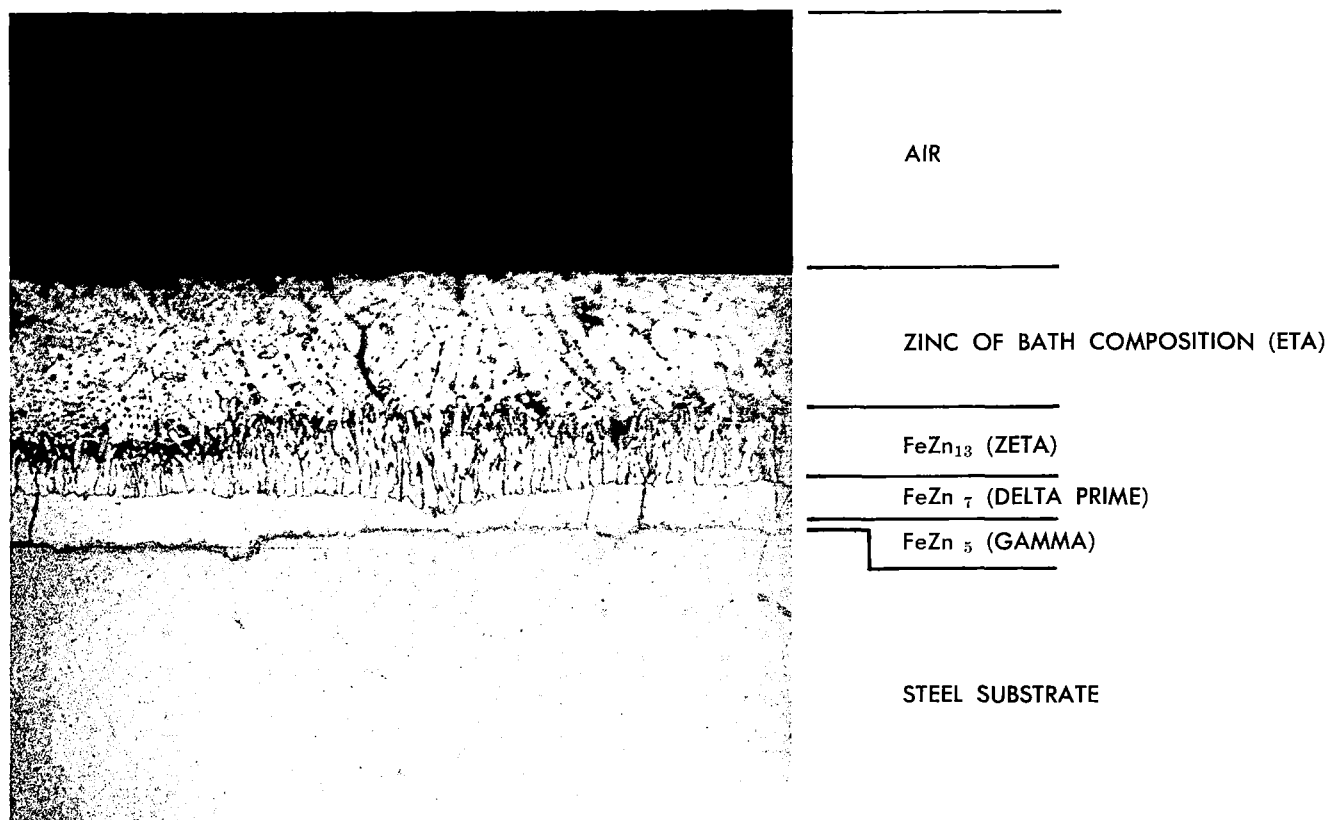
Figure 5-1.   Steel Hot Dipped in Zinc (Cross Section Magnified Approximately 500 Diameters)

lytic cell are acid sulphate and alkaline cyanide solutions. Zinc should be deposited directly on the cleaned surface of the base metal. If the base metal is a corrosion-resisting steel, a nickel coat under the zinc is permissible. One advantage of the electroplated zinc-coating process is the excellent control that can be exercised over weight and thickness of the zinc plating. Electrogalvanized coatings are more pure and have better ductility and adherence than hot-dip coatings; however, they are seldom thicker than 0.001 inch, and such thin coatings provide corrosion protection for a much shorter time period than do hot-dipped coatings. There are several classes and types of zinc-electroplating techniques; for details, see QQ-Z-325.

Electrogalvanized steel must be painted if subjected to outdoor exposure, but it cannot be satisfactorily painted without proper surface treatment. The manufacturer can furnish advice regarding the painting requirements and processes for painting of electrogalvanized steel. Also, refer to Chapter IV, paragraph 4.15.

5.7   SHERARDIZING

Sherardizing is best suited to small articles such as nuts and bolts. The cleaned items are packed in zinc powder in a drum which is then sealed air tight. The drum is slowly rotated and heated to 700°F while the items tumble in the zinc dust. This dust is approximately 90 percent metallic zinc and 10 percent zinc oxide. The coating rate is about 0.5 ounce per square foot per 3 hours and results in a coating thickness of 0.001 inch. The resulting coat is a zinc-iron alloy ranging from approximately 5 to 18 percent iron at the interface.

5.8   METALLIZING (FLAME SPRAY)

Zinc coatings can be applied in the field where hot-dip or electroplated zinc is impossible. It is accomplished by metallizing or flame spraying. Metallizing appears to offer excellent control over corrosion even in harsh environments. Metal spraying is discussed separately and in detail in this chapter. For details on metallizing, see Chapter V, Part C, MIL-M-6874, and MIL-M-3800.

5.9   CEMENTATION

Cementation is heating the metal to be coated while surrounded by another metal or nonmetal, usually in powdered form. The heat is held to a temperature somewhat below the distortion temperature of the more fuseable of the two. The interface is somewhat similar to hot dipping because there is an alloying action at the surface of the treated metal. The metals interdiffuse upon intimate contact with each other in the proper temperature zone. Zinc dust alloys with iron surfaces

at relatively low temperatures. Zinc cementation is also known as sherardizing. Cementation dusts used in the main are zinc, chromium, and aluminum. The protection provided by cementation does not equal that of hot dipping.

5.10   VAPOR DEPOSITION

Vapor deposition might also be termed vapor condensation where the vapors of the coating metal condense on the surface of the metal receiving the treatment. The process usually is under low pressure or vacuum type conditions. The treatment metal is vaporized by electrical ovenheating. Metal deposition may be quite rapid, and there is some possible control over thickness. Application is to special projects such as coating electrical capacitor papers with zinc, coating telescope mirrors with aluminum, and multiple coatings for thermal control on satellites.

5.11   NATURAL FILM

The nature of the corrosion film on the surface of any zinc coating is determined by the ingredients of the natural environment and the pollutants added by man. These factors determine the rate of corrosion attack and the protective life of the zinc coating. Atmospheric environmental factors such as frequency and intensity of rainfall; frequency, amount, and duration of dew and mist; and the saline content of airborne moisture are all significant in affecting the protective film. Pollution of the atmosphere with gaseous and solid constituents also has an impact on the corrosion of the zinc coating. If the coating is broken as a result of mechanical damage, the zinc serves as an effective sacrificial coating and provides cathodic protection for the base metal. The electrochemical protection of the steel substrate at discontinuities in the zinc coatings depends largely on the conductivity of the electrolyte. Although many factors exert an influence, the rate at which galvanized steel corrodes in outdoor exposure is governed mainly by the frequency and duration of moisture contact, or, in other words, the presence of an electrolyte. When galvanized steel is exposed to the weather, the bright zinc surface becomes dull. This change in appearance, which is accompanied by a roughening of the surface, is caused by a film formed by reaction of the zinc with the environment. This surface film slows further change in the character of the zinc somewhat and results in long life for the galvanized steel. Discoloration of the galvanized surface caused by a mixture of basic carbonates of zinc and zinc oxides or hydroxides undoubtedly results from electrochemical corrosion of the zinc. Such corrosion occurs when differentials in humidity, water, films, illumination, bacteria, and oxygen concentration on the

surface stabilize anodic and cathodic areas. Zinc hydroxides then form at the anodic areas.

The protective value of the various zinc coatings on steel is approximately proportional to the coating thickness. Uniformity of coating is also a very important consideration. The corrosion rate of the zinc on galvanized steel is practically linear in dry, normal, humid, and harsh environments. This does not mean the life spans of the coatings in the different environments are the same. It does mean that a double weight or thickness of zinc coating can be expected to last twice as long before rust attacks the base metal in any particular environment.

PART C.   METALLIZING BY FLAME SPRAY

Metallizing, known as a cold process of coating with flame-sprayed metal, presents a flexible, practical, and effective means of protection against corrosion attack. The great advantage of the metallizing process is that it employs portable equipment. (Figure 5-2 details the equipment layout for flame spraying metal wire.) This makes it adaptable for applying protective metallic coatings to large complex assemblies and structures. It is not economically feasible to attempt hot-dip galvanizing or electroplating of assembled structures in the field, but pure metal protective coats of aluminum or zinc can be applied to such structures by flame-spray metallizing.

5.12 PROPERTIES OF SPRAYED METALS

Metallized coatings have unique structures and desirable properties. They are formed by layers of thin flakes as the atomized globules of the sprayed metal strike the target area with considerable speed and impact. Initially, each particle is a tiny casting which has solidified very rapidly and acquired an oxide film during its short journey from the gun nozzle to the metal surface. On impact, the particles are instantly deformed into thin platelets or flakes. Their impact energy permits the particles to conform to the surface contour and bond to the prepared surface by mechanical interlocking with surface irregularities. Where the oxide film is disrupted on impact, it is reestablished by cold welding, and metal-to-metal contact is regained.

The bond is almost entirely mechanical in nature. The base metal presents a degree of roughness which depends upon the method used for surface preparation. Most of the sprayed metal particles which strike the surface are sufficiently plastic to conform to and interlock with the surface irregularities. Although a small amount of fusion may take place between the particles of sprayed metal and the base metal, the overall effect of such fusion is very significant. This unique structure changes the physical characteristics of the metal. The ductility, elongation, and tensile strength of the sprayed metal are greatly reduced when compared with the same metal in cast form. The impact of this reduction on metallized sections of a complex structure such as an antenna sprayed for corrosion control should be checked. There is some precedent, however, because many bridge structures have been metallized for corrosion control, and the performance of the sprayed metal is very good. (See figures 5-3, 5-4, and 5-5 for cross-section enlargements of 0.003 inch Al with sealer on steel, 0.0009 inch Al on steel with no sealer, and 0.003 inch Zn with sealer on steel, respectively.)

5.13 SPRAYABLE METALS

All metals that are available in wire form can be sprayed, and several of them are quite effective in controlling corrosion. Metals in wire-form that can be flame sprayed include stainless steel, aluminum, zinc, cadmium, lead, tin, nichrome, nickel, monel, tantalum, molybdenum, silver, and gold. These metals are applied for decoration, wear resistance, or corrosion control. The corrosion control that can be obtained from properly applied sprayed metals can be rated as good to excellent even for a harsh environment.* Tests have demonstrated that metallized aluminum sealed with vinyl is an excellent corrosion-control method for saltwater exposure applications. Metallized coatings of aluminum and zinc are commonly used for protecting iron and steel against the corrosion ravages of salt- and fresh-water immersion. These coatings provide protection against corrosion not only by covering the surface with a corrosion-resistant metal, but also by cathodic action because both aluminum and zinc are anodic to iron and steel.

5.14 SPRAYED METAL TEST RESULTS

The American Welding Society report AWS C 2.11-67, published in 1967, gives detailed results of a 12-year test of sprayed aluminum and zinc coatings on steels which were exposed to the

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* The four MSFN environments are defined in table 2-4.
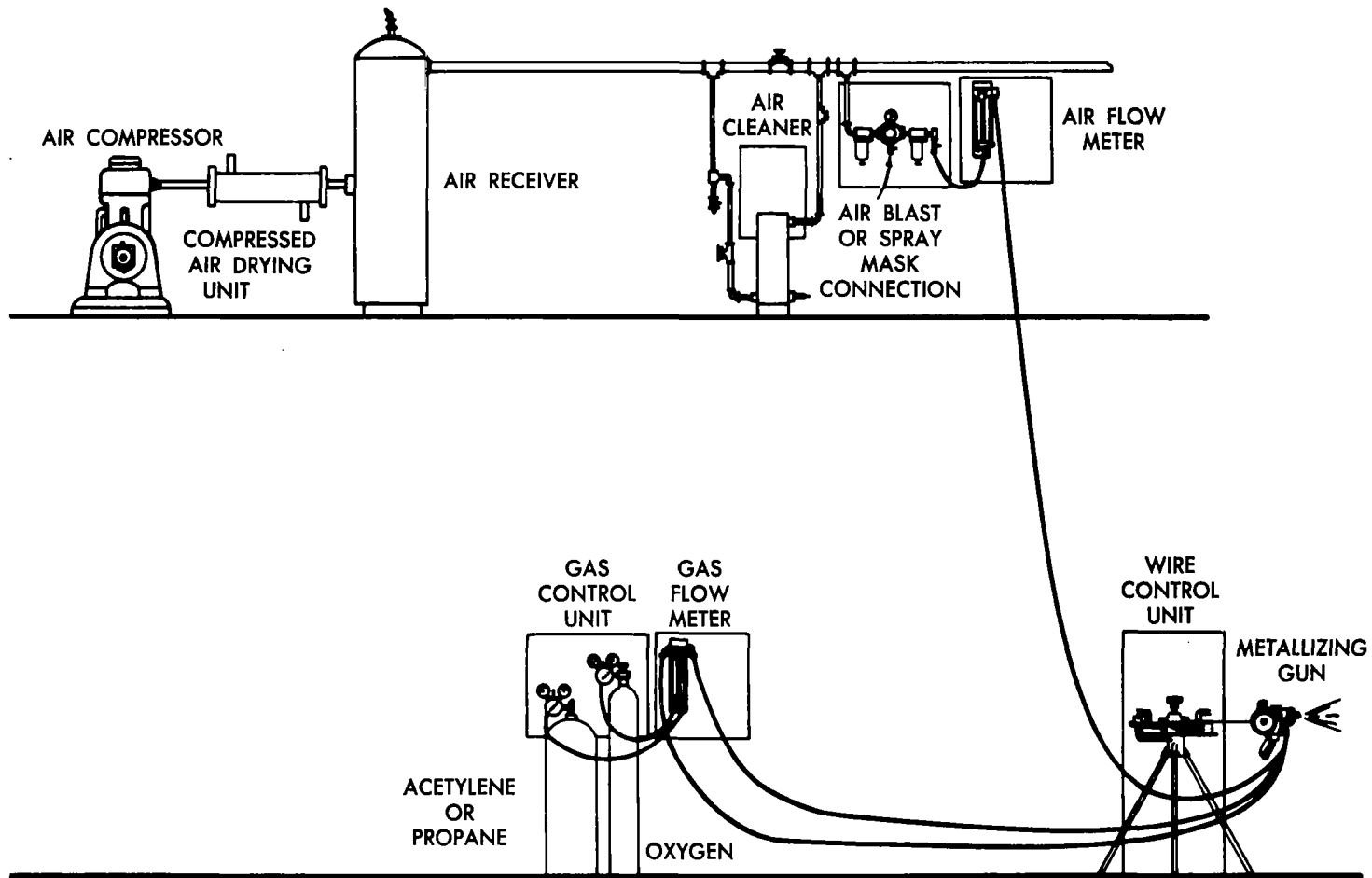
Figure 5-2. Metallizing Facility Components

AIR COMPRESSOR

COMPRESSED
AIR DRYING
UNIT

AIR RECEIVER

AIR
CLEANER

AIR BLAST
OR SPRAY
MASK
CONNECTION

AIR FLOW
METER

GAS
CONTROL
UNIT

GAS
FLOW
METER

WIRE
CONTROL
UNIT

METALLIZING
GUN

ACETYLENE
OR
PROPANE

OXYGEN

MOUNTING MATERIAL

ALUMINUM VINYL PAINT 2 COATS—1 MIL ⎫
⎬ SEAL
POLYVINYL BUTYRAL WASH PRIMER—0.5 MIL ⎭

FLAME-SPRAYED ALUMINUM—3 MILS Σ
2 PASSES OF SPRAY GUN

STEEL SUBSTRATE

NOTE: THIS CROSS SECTION IS POLISHED BUT NOT DYED OR ETCHED; IT IS NEW,
AND HAS NOT BEEN EXPOSED TO ENVIRONMENT.

Figure 5-3. Sealed Aluminum System (Cross Section Photographed at 260 Diameter Magnification)
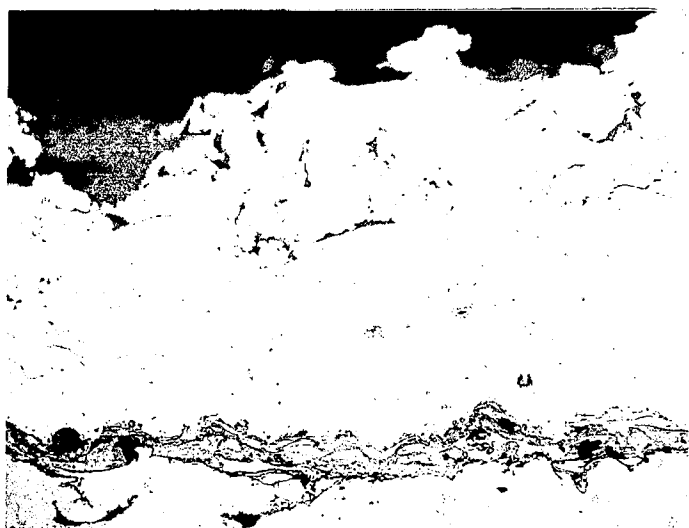
MOUNTING MATERIAL

FLAME-SPRAYED ALUMINUM—9 MILS Σ
MULTIPLE PASSES OF SPRAY GUN

FLASH COATING OF FLAME-SPRAYED
LOW-CARBON STEEL

STEEL SUBSTRATE

NOTE: THIS CROSS SECTION IS POLISHED BUT NOT DYED OR ETCHED; IT IS NEW,
AND HAS NOT BEEN EXPOSED TO ENVIRONMENT.

Figure 5-4. Unsealed Aluminum System (Cross Section Photographed at 260 Diameter Magnification)
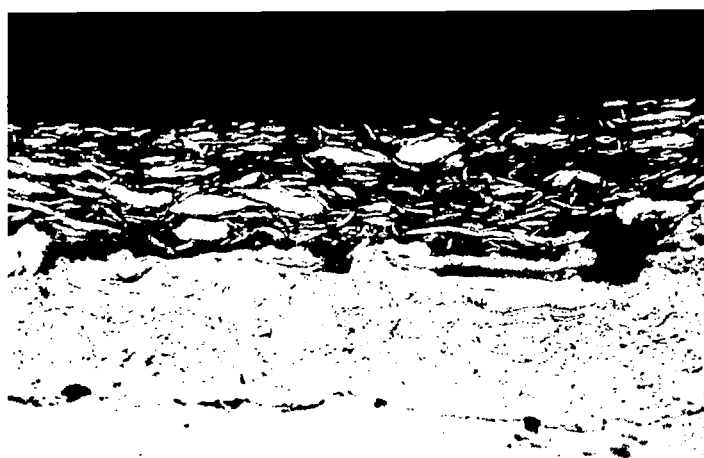
MOUNTING MATERIAL

ONE COAT OF ALUMINUM VINYL—2 MILS ⎫
POLYVINYL BUTYRAL WASH PRIMER—0.5 MIL ⎬ SEAL

FLAME-SPRAYED ZINC—3 MILS Σ

STEEL SUBSTRATE

NOTE: THIS CROSS SECTION IS POLISHED BUT NOT DYED OR ETCHED; IT IS NEW, AND HAS NOT BEEN EXPOSED TO ENVIRONMENT.

Figure 5-5. Sealed Zinc System (Cross Section Photographed at 260 Diameter Magnification)

atmosphere at International Nickel's test area at Kure Beach in North Carolina. Although all test panels exhibited good corrosion resistance, the sprayed metal that was sealed with a wash primer and vinyl top coat was in the best condition. The aluminum sprayed and sealed test plates were in excellent condition. In the salt-water immersion tests, the staying power of zinc-sprayed metal ran second to aluminum. The difference lies in the oxidation mechanisms of Al and Zn. The zinc oxide coating does not appreciably retard the oxidation rate; the zinc continues to sacrifice or oxidize. The aluminum-sprayed coating oxidizes to form an inert film (Al_2O_3), which greatly retards further attack. The film is stable unless broken or ruptured by mechanical means or is subjected to certain chemicals as described in Chapter III, Part A. While the cost of an aluminum coating is less than zinc of equal thickness, aluminum requires much more thorough sandblasting for surface preparation. In addition, it is not recommended that aluminum be applied less than 0.003 inch in thickness.

5.15 CORROSION CONTROL WITH SPRAYED METAL

Metallizing has the advantage that much thicker coatings of the protective metals can be applied more rapidly than by other surface treatment methods such as hot dipping or electroplating; this is significant because corrosion protection is often in direct relation to the protective-coating thickness. The life of a flame-sprayed zinc coating is almost directly proportional to the thickness of the coat. Aluminum and cadmium, the other two metals commonly sprayed for corrosion control, also show a fairly direct relationship between the life of the coating and its thickness. Because of the porosity of metallized coatings, it is customary to apply a greater thickness of protective metal than for dipped or plated coatings. The thicknesses of plated and dipped coatings are limited by processing techniques. The magnetic thickness gauge is a small direct reading gauge for measuring the thickness of any nonmagnetic coating such as zinc or aluminum on iron or steel and a handy instrument for quality control.

An ideal corrosion-control system will protect steel under the most severe conditions. Those conditions could involve salt water, salt spray, or saline aerations. Such a system is available in flame-sprayed aluminum, sealed with a wash primer and a compatible vinyl paint. Wash primers have the advantage of displacing moisture to some extent and should always be used if there is any question of moisture in the sprayed metal. Unfortunately, some wash primers are too reactive for use on sprayed metal. Formulations suitable for galvanized sheet may be too acidic for use with sprayed coatings of zinc. No wash primer should be used until it has been positively determined that it is suitable for use on sprayed metal. In no instance should a wash primer containing more than an absolute maximum of 4 percent H_3PO_4 be used.

Painting with a wash primer and top coat to seal the flame-sprayed metal plays a vital part in completing the protective coat when aluminum is flame sprayed onto steel. The aluminum is slightly porous; the sealing materials fill up the pores of the coating and establish a permanent barrier. When chosen correctly and applied properly, the sealer adds very little to the thickness of the previously deposited aluminum coating. The corrosion control afforded by flame-sprayed metals was first used in Europe, probably because the original idea of applying metallic coatings by spraying was conceived by M. U. Schoop of Zurich, Switzerland, in 1910. In Europe, where much more metallizing is aimed at solving corrosion problems, large bridges, window frames, lamp poles, boat hulls, water tanks, and gas cylinders are flame sprayed.

5.16 PROCEDURES AND TECHNIQUES

In preparing a surface for flame spraying aluminum, there are no options regarding the grade of surface preparation; it must be whiteblasted as nothing else will suffice as a substrate preparation. In addition, the whiteblasted surface must be perfectly dry before the flame-sprayed metal is applied. The drying process can be accomplished by the metallizing gun, merely by releasing the metal-feeding trigger and drying the desired section with the gas flame. Whenever there is any doubt whether a surface is dry, it should be warmed before flame spraying. The ambient temperature may be well above the dewpoint temperature but the metal itself, because of shadows, the mass involved, etc., may be below the dew point, creating the danger of an invisible moisture film forming on the metal. Flame spraying on a moist metal surface must be avoided; only dry, clean metal surfaces are suitable. Heating a surface to 100° F will drive off atmospheric moisture. Some highly experienced flame-spray craftsmen prefer to heat the surface from 175 to 200° F before starting to metallize; this results in an improved bond. In addition to preventing atmospheric-moisture condensation, the higher preheat prevents water vapor originating in the combustion of the gas-oxygen flame from condensing on the base metal or the preceding pass of sprayed metal.

A metallizing gun is the most important item of equipment needed for metallizing work. The gun is a mechanical device for feeding, melting, and atomizing wire of various metals and spraying the atomized particles at high velocity onto the surface being coated. Guns of various sizes using wire from approximately 0.090 to 0.188 inch in diameter are available for different types of work. Guns designed especially for applying coatings for corrosion protection are capable of spraying approximately 17 pounds of aluminum or 60 pounds of zinc

per hour. Other items of supplementary equipment for a metallizing unit consist of an air compressor, an air-control unit including filter and regulator, tanks of oxygen and acetylene or other fuel gas, a gas-control unit with suitable pressure regulators, a gas-flow meter, and a wire-control unit for handling coils of the metallizing wire. The actual application of the metal, the flame-spraying process, is not too demanding of the craftsman or technician using the gun, but the gas pressure, rate of wire feed, spray pattern, and speed of movement all have a direct bearing on the quality of the coating. One prominent manufacturer has developed 16 systems for flame spraying aluminum and 8 for zinc. Therefore, with all the variations and techniques, it is only reasonable that the proper use of the gun requires a craftsman who uses it frequently to master the techniques.

5.17 THE COST OF FLAME SPRAYING

The cost of flame spraying aluminum to control corrosion of iron and steel is very reasonable and competitive or it is very high, depending on the researcher's analysis of initial and lifetime costs. Because a sealed aluminum-sprayed coating of 0.003 inch to 0.006 inch thick has 15 to 20 years of life when protecting steel in a saline contaminated atmosphere (harsh environment), it is very competitive. The following data on costs are applicable for the continental United States for 1967 and 1968.

5.17.1 COST OF METALLIZING IN THE SHOP

5.17.1.1 FLAT SURFACES

a. The worker can cover approximately 1000 square feet per hour when spraying aluminum 0.001 inch thick.

b. The efficiency of aluminum spray is approximately 89 percent. (89 percent of total spray adheres to metal.)

c. The total cost of flame spraying aluminum in the shop 0.004 to 0.006 inch thick on a flat surface ranges from $0.40 to $0.80 per square foot for 1000 square feet or more. (The cost does not include surface preparation.)

5.17.1.2 COMPLICATED SURFACES

a. The worker can cover approximately 500 square feet per hour when spraying aluminum 0.001 inch thick.

b. The efficiency of aluminum spray ranges from 40 to 70 percent.

c. The total cost of flame spraying aluminum in the shop 0.004 inch to 0.006 inch thick on a complicated surface ranges from $0.50

to $0.90 per square foot for 1000 square feet or more. (The cost does not include surface preparation.)

5.17.2 COST OF METALLIZING IN THE FIELD

5.17.2.1 FLAT SURFACES

a. The worker can cover 600 to 900 square feet per hour when spraying aluminum 0.001 inch thick.

b. The efficiency of aluminum spray ranges from 75 to 85 percent.

c. The total cost of flame spraying aluminum in the field 0.004 to 0.006 inch thick on a flat surface ranges from $0.50 to $1.00 per square foot for 1000 square feet or more. (The cost does not include surface preparation.)

5.17.2.2 COMPLICATED SURFACES

a. The worker can cover 300 to 500 square feet per hour when spraying aluminum 0.001 inch thick.

b. The efficiency of aluminum spray ranges from 40 to 80 percent.

c. The total cost of flame spraying aluminum in the field 0.004 to 0.006 inch thick on a complicated surface ranges from $.75 to $1.50 per square foot for 1000 square feet or more. (The cost does not include surface preparation.)

5.17.3 OTHER COST DATA

a. The aluminum wire required to spray 10,000 square feet 0.003 inch thick is approximately $300.

b. The approximate cost for proper surface preparation is $0.15 per square foot for 1000 square feet or more.

c. The specialized equipment required for the above spraying mode includes oxygen-acetylene regulators, hoses, meters, controls, and 7E model gun. The total purchase price ranges from $2000 to $2500.

The question of metallizing by contract or with in-house personnel should be resolved after studying the volume of work to be done. If the work load is large enough to keep a trained operator busy to the extent that his techniques and craftsmanship are maintained, then an in-house effort is probably the best approach. If a contract effort is decided upon, the contract specifications should be very exacting.

5.18 SPECIFICATION OUTLINE FOR METALLIZING

5.18.1 SURFACE PREPARATION

The initial cleaning action must remove all oils, greases, hydrocarbons, and fatty residues. Depending on the size and location of the item, degreasing can be accomplished by pickling (SSPC-SP8-63). A large structure such as an antenna in the field can be cleaned of hydrocarbon compounds very effectively by the use of solvents and steam cleaning, (SSPC-SP1-63). The degreasing or steam-cleaning procedure must precede sandblasting.

Sandblasting is probably the fastest, most economical method to clean old paint, rust, etc., from large and complicated steel structures. The highest quality surface is whiteblast (SSPC-SP5-63). Metallizing cannot achieve the desired bond to the base metal unless the surface is cleaned of all contaminants and anchor etched. Whiteblast accomplishes both tasks. The grit used for the sandblasting should also be specified because ordinary rounded sand grains will not cut properly. Washed, salt-free angular silica sand or crushed garnet that will pass through mesh sizes 20 to 40 are acceptable. The sand must be free from feldspar and other mineral agents which break down and remain on the surface. The equipment for the sandblasting should also be specified. The nozzle sizes $\frac{1}{8}$ or $\frac{1}{4}$ inch venturi type are suitable. The hose lengths should be 25 feet longer than the highest or most remote point to be blasted. The compressor should provide moisture- and oil-free air that discharges from the nozzles at 80 or 100 pounds per square inch. After blasting, the surface must be air cleaned to remove all dust.

5.18.2 METALLIZING

The metallizing process must begin before any contaminants whatsoever foul the whiteblast surface; in harsh environments, this means almost immediately. The surface must be dried before spraying; this can be accomplished by a metallizing gun. An approved metal spray gun using 99 percent pure aluminum wire $\frac{1}{8}$ or $\frac{3}{16}$ inch in diameter is required. The coatings must be applied in multiple layers, and in no instance should less than two controlled spray passes be made. The finished coating must not be less than 0.004 inch in thickness. The coating should be inspected with an approved magnetic thickness gauge as soon as possible after each section is completed. Any area requiring additional spraying must be free from all contaminants.

The specifications must also include the seal coats for the sprayed metal. The first coat must

be affixed by pressurized paint spray guns and should be a wash-coat primer applied to a noncontaminated surface. The final coat can be a high-quality vinyl paint affixed by pressurized paint spray guns to a noncontaminated surface. The role of the primer is to fill up the pores of the sprayed metal; the vinyl top coat should be 2 mils in thickness.

5.19 FLAME SPRAYING MSFN ANTENNAS

Flame spraying or metallizing with 99 percent pure aluminum and proper sealing of the porous coating has many features which would promote good corrosion control at the MSFN tracking facilities operating in harsh environments. The system, when applied by a craftsman, and quality controlled, offers great flexibility. A large or small area can be flame sprayed with minimum setup and stow time for the required equipment; the items of specialized equipment are few and not bulky; the raw materials required are readily available in most areas of the world; and, perhaps most important, it does control corrosion. For additional details on flame spraying or metallizing, refer to MIL-M-6874 (Change 1) and MIL-M-3800.

APPENDIX

GENERAL LISTING OF SPECIFICATIONS DEALING DIRECTLY OR INDIRECTLY WITH SURFACE TREATMENT FOR CORROSION CONTROL

FEDERAL
SPECIFICATIONS

QQ-A-250	Aluminum Alloy Plate and Sheet, General Specification for
QQ-C-320	Chromium Plating (Electrodeposited)
QQ-N-290	Nickel Plating (Electrodeposited)
QQ-P-35	Passivation Treatments for Austenitic, Ferritic and Martensitic Corrosion-resisting Steel (Fastening Devices)
QQ-P-416	Plating, Cadmium (Electrodeposited)
QQ-S-365	Silver Plating, Electrodeposited, General Requirements for
QQ-S-571	Solder, Tin Alloy, Lead-tin Alloy and Lead Alloy

MILITARY
SPECIFICATIONS

MIL-P-116	Preservation, Methods of
MIL-T-152	Treatment, Moisture- and Fungus-resistant, of Communications, Electronic, and Associated Electrical Equipment
MIL-V-173	Varnish, Moisture- and Fungus-resistant (for the Treatment of Communications, Electronic, and Associated Electrical Equipment)
MIL-F-495	Finish, Chemical, Black, for Copper Alloys
MIL-R-3065	Rubber, Fabricated Parts
MIL-M-3171	Magnesium Alloy, Processes for Pretreatment and Prevention of Corrosion on
MIL-D-3464	Desiccants, Activated, Bagged, Packaging Use and Static Dehumidification
MIL-S-3927	Sealing Compound, Thread, Polymerizing, Room Temperature
MIL-S-5002	Surface Treatments and Metallic Coatings for Metal Surfaces of Weapon Systems
MIL-C-5541	Chemical Films and Chemical Film Materials for Aluminum and Aluminum Alloys
MIL-S-6855	Synthetic Rubber Sheets, Strips, Molded or Extruded Shapes

MIL-W-6858	Welding, Resistance, Aluminum, Magnesium, Non-Hardening Steels or Alloys, Nickel, Alloys, Heat-resisting Alloys, and Titanium Alloys, Spot and Steam
MIL-I-6869	Impregnants for Aluminum Alloy and Magnesium Alloy Castings
MIL-S-6872	Soldering Process, General Specifications for
MIL-S-7124	Sealing Compound, Elastomeric, Accelerator Required, Aircraft Structure
MIL-B-7883	Brazing of Steels, Copper, Copper Alloys, and Nickel Alloys
MIL-P-8116	Putty, Zinc Chromate, General Purpose
MIL-S-8516	Sealing Compound, Synthetic Rubber, Electric Connectors and Electric Systems, Accelerator Required
MIL-I-8574	Inhibitors, Corrosion, Volatile, Utilization of
MIL-P-8585	Primer Coating, Zinc Chromate, Low-moisture-sensitivity
MIL-W-8604	Welding of Aluminum Alloys, Process for
MIL-W-8611	Welding, Metal Arc and Gas, Steels, and Corrosion and Heat Resistant Alloys, Process for
MIL-A-8625	Anodic Coatings, for Aluminum and Aluminum Alloys
MIL-C-8837	Coating, Cadmium (Vacuum Deposited) (ASG)
MIL-W-8939	Welding, Resistance, Electronic Circuit Modules (ASG)
MIL-T-10727	Tin Plating, Electrodeposited or Hot-dipped, for Ferrous and Nonferrous Metals
MIL-S-11030	Sealing Compound, Noncuring, Polysulfide Base
MIL-C-11796	Corrosion Preventive Compound, Petrolatum, Hot Application
MIL-T-12664	Treatment, Fungus Resistant, Paranitrophenol, for Cork Products
MIL-T-12879	Treatments, Chemical, Prepaint and Corrosion Inhibitive, for Zinc Surfaces
MIL-S-13165	Shot Peening of Ferrous Metal Parts
MIL-P-13380	Primer, Weld-through
MIL-L-13762	Lead Alloy Coating, Hot-dip (for Iron and Steel Parts)
MIL-L-13808	Lead Plating (Electrodeposited)
MIL-F-14256	Flux, Soldering, Liquid (Rosin Base)
MIL-C-14550	Copper Plating (Electrodeposited)
MIL-P-15930	Primer Coating, Shipboard, Vinyl-zinc Chromate (Formula No. 120—for Hot Spray)
MIL-C-16173	Corrosion Preventive Compound, Solvent Cutback, Cold Application
MIL-C-16555	Coating Compound, Strippable, Sprayable
MIL-I-16923	Insulating Compound, Electrical, Embedding
MIL-W-18142	Wood Preservative Solutions, Oil-soluble, Ship and Boat Use
MIL-W-18326	Welding of Magnesium Alloys, Gas and Arc, Manual and Machine Processes for
MIL-S-22473	Sealing, Locking and Retaining Compounds, Single-Component
MIL-C-22750	Coating, Epoxy-Polyamide
MIL-C-22751	Coating System, Epoxy-polyamide, Chemical and Solvent Resistant, Process for Application of
MIL-P-22808	Paint, Epoxy, Hydraulic-fluid Resistant
MIL-T-23142	Tape, Pressure-Sensitive Adhesive, for Dissimilar Metal Separation
MIL-C-23217	Coating, Aluminum, Vacuum Deposited (ASG)
MIL-P-23377	Primer Coating, Epoxy-polyamide, Chemical and Solvent Resistant
MIL-L-23398	Lubricant, Solid Film, Air Drying
MIL-P-23408	Plating, Tin-cadmium (Electrodeposited)
MIL-C-23411	Corrosion Preventive Compound Clear

MIL-S-23586	Silicone Rubber Compound, Room Temperature Vulcanizing
MIL-C-26074	Coating, Nickel-phosphorus, Electroless Nickel, Requirements for
MIL-M-45202	Magnesium Alloy, Anodic Treatment of
MIL-G-45204	Gold Plating (Electrodeposited)
MIL-P-45209	Palladium Plating (Electrodeposited)
MIL-S-45743	Soldering, High Reliability, Electrical Connections, for Guided and Ballistic Missile Systems, with Electrically Heated Soldering Irons, and Resistance Soldering Apparatus, Procedures for
MIL-L-46002	Lubricating Oil, Contact and Volatile Corrosion Inhibited
MIL-L-46010	Lubricant, Solid Film, Heat Cured, Corrosion Inhibiting
MIL-C-46057	Coating, Polyurethane
MIL-I-46058	Insulating Compound, Electrical (for Coating Printed Circuit Assemblies)
MIL-P-46067	Plastic Embedding Compound, Epoxy, Rigid
MIL-P-46076	Plastic, Polyurethane, Flexible Potting and Holding Compound
MIL-R-46085	Rhodium Plating, Electrodeposited
MIL-R-46092	Rubber, Silicone, Encapsulating Compound
MIL-S-46844	Solder Bath Soldering of Printed Wiring Assemblies, Automatic Machine Type
MIL-P-46847	Plastic Material, Foamed Polyurethane for Encapsulating Electronic Components
MIL-P-52192	Primer Coating, Epoxy
MIL-C-52210	Coating, Epoxy, Spray Type, for Printed Circuitry

MILITARY STANDARDS

MIL-STD-186	Protective Finishing Systems for Rockets, Guided Missiles, Support Equipment and Related Materials
MIL-STD-276	Impregnation of Porous Nonferrous Metal Castings
MIL-STD-446	Environments for Electronic Parts, Tubes and Solid State Devices
MIL-STD-454	Standard General Requirements for Electronic Equipment
MIL-STD-810	Environmental Test Methods
MIL-STD-1276	Lead, Weldable, for Electronic Component Parts

ARMY REGULATIONS

AR-705-15	Operation of Material Under Extreme Conditions of Environment

MICOM REGULATIONS

MICOM Regulation 705-8	Prevention of Weapon System Deterioration

SOCIETY OF AUTOMOTIVE ENGINEERS*

AMS 2401	Plating—Cadmium, Low-hydrogen Content Deposit
AMS 2416	Plating—Nickel-cadmium, Diffused

* Copies of AMS specifications may be obtained from the Society of Automotive Engineers, Inc., 485 Lexington Avenue, New York, New York, 10017.

CHAPTER VI.   RADOMES

INTRODUCTION

6.1   GENERAL

It is quite possible to erect an antenna that has a minimum of corrosion-control features and yet will experience a very low corrosion rate. Erecting the antenna at a location where the relative humidity is 25 percent or less for 95 percent of the time will permit extremely low corrosion rates. There are such places on earth, but they are not located where many of the MSFN antennas are required. One exception is Goldstone, California, the site of an 85-foot, X-Y axis Apollo antenna. Such locations are ideal because corrosion rates are minimal. Antennas are also located in very harsh environments, such as Coopers Island in Bermuda, where the corrosion rates are extremely rapid. Today it is possible to surround a Coopers Island antenna with a Goldstone environment that will minimize corrosion rates; this feat is accomplished by using a radome. Covering an antenna that was not originally designed to be integrated with a radome is expensive. The integrated antenna-radome design is a sound economic approach, not only for the lifetime savings but also, in many cases, for the initial cost. A radome is usually not envisioned as a corrosion-control technique, but when it can save between $50,000 and $100,000 in 10 years on a 30-foot antenna in a harsh environment, it should be investigated in great detail. Section VI summarizes the advantages and disadvantages of the radome from electronic degradation through structural savings to corrosion control.

6.2   TECHNICAL

The use of a radome can almost eliminate the corrosion attacks experienced by an unprotected radar, but new responsibilities arise. Keeping the radome inflated, sealed against leakage, air conditioned, or painted, imposes new operational and maintenance workloads. The scope of the new work depends upon the type of radome selected and the station location. Facilities engineers and technicians feel that the additional workload is more than offset by the improved corrosion control and the constant environment favorable to maintenance work.

PART A.   TYPES OF RADOMES

A radome has one purpose: it permits the control of environment around an antenna. With environmental control, the antenna structure and support equipment are protected from high winds, water, snow, ice, sand, salt, and corrosion. Where the natural environment of an antenna is so hostile that it can degrade the mission capability by storm damage, by distortion and vibration resulting from wind velocity, or by corrosion, the use of a radome should be studied. A substantial percentage (10—20 percent) of the antenna construction cost appears justifiable to negate the hostility. Much documentation exists on storm damage and corrosion damage to antennas. The Air Force and Navy files are especially well documented.

A radome, properly designed, fabricated, and installed permits the creation of an artificial environment. This manmade environment is ideal for the physical structure and equipment, but there is a loss involved: the radome destroys a certain amount of the electrical sensitivity and power of the antenna. Each radome has electrical characteristics that degrade the antenna's transmission and reception performances. An interesting aspect of radome structures is the variation in the pointing accuracy, noise level increases, etc., that the different types of radomes will cause.

This chapter discusses the various types of radomes, their strengths, weaknesses, and electrical characteristics. There are radical differences in the design of these structures. Each type of radome interferes with electromagnetic wave propagation in a rather definite manner because of such influencing factors as skin thickness, water absorption, number and mass of seams or

ribs, etc. Large radomes (60 feet or greater in diameter) are of two classes: rigid and inflatable (air-supportable).

Rigid Radomes	*Air-inflated Radomes*
Metal space frame (figure 6-1)	Single wall (figures 6-2 & 6-3)
Plastic space frame	Dual wall (figure 6-4)
Thin wall, stressed-skin plastic	
Thick-skin frame	

Each type of radome involves considerations of economics, structural strength, signal degradation, antenna protection, and maintenance. Paragraphs 6.3.1 through 6.3.2.2 describe these characteristics.

6.3 RIGID RADOMES

6.3.1 METAL SPACE FRAME

a. It is suitable for large antennas because of the structural strength; radomes as large as 500 feet in diameter seem possible.

b. It is the state-of-the-art for large microwave antennas (shortwave length —20 centimeters or less).

c. It has metal ribs; a loss of axial gain of less than 0.5 decibel resulting from aperture blockage seems possible in radomes as large as 200 feet in diameter.

d. The random placement of ribs reduces effects to existing antenna sidelobes.

e. The scattering of energy results from discontinuities at flanges and ribs.

f. It withstands winds up to 150 miles per hour.

g. The corrosion rates at the aluminum rib joints in a harsh environment are unknown but could be minimized with proper treatment of aluminum and environmental sealing.

h. The conditioning of air in harsh environments may be required to control the humidity and saline content of air inside the radome.

i. Maintenance appears limited to infrequent sealing of joints where membranes and ribs meet.

j. The Haystack radome designed 10 years ago contributes approximately a 1.1 decibel blockage and adds about 10° K to the noise level. The present metal space frame designs have a blockage between 0.4 and 0.6 decibel and add about 5° K to the noise level.

k. The approximate cost in the Boston, Mass., area for a 55-foot radome is $65,000; for a 125-foot radome, it is $400,000.

6.3.2 PLASTIC SPACE FRAME

a. It is based on geodesic dome design.

b. Individual triangles or hexagons and pentagons make up the frame.

c. Skin panels $\frac{1}{16}$-inch thick are fitted across the frame.

d. Regular placement of ribs results in increased off-axis sidelobes.

e. Scattering of energy results from discontinuities at flanges and ribs.

f. The plastic space frame may be considered obsolete because of recent refinements of the metal space frame.

6.3.3 THIN WALL, STRESSED-SKIN PLASTIC

a. The skin is of molded, orange-peel-like sections, laminated together to form a radome.

b. The seam thickness varies from $\frac{1}{4}$ to $\frac{1}{2}$ inch.

c. It is excellent for use with antennas radiating in the 200 megahertz region.

d. The wall thickness is too great for use with antennas that transmit in the microwave range.

6.3.4 THICK-SKIN FOAM

a. Igloo-type structure.

b. Wall blocks of expanded dylite-polystyrene foam.

c. Thickness of foam is determined by structural needs.

d. Blocks covered on both sides with a layer of fiberglass.

e. Dielectric constant of foam is near unity.

f. Reduced discontinuity at the edges of panels, less aperture blockage.

g. Problem arises from water entrapped in the polyfoam, unpredictable phase delay and loss.

h. Present thick-wall construction appears to be unsuitable for MSFN antennas.

6.4 AIR-SUPPORTED RADOMES

6.4.1 SINGLE WALL

a. The air-tight fabric partial sphere is supported entirely by the pressure of the internal air.

b. The sphere material is usually dacron fabric coated with hypalon or vinyl-coated nylon.

c. A blower is required to support the radome. Air conditioning may be incorporated in the air supply. An air lock is
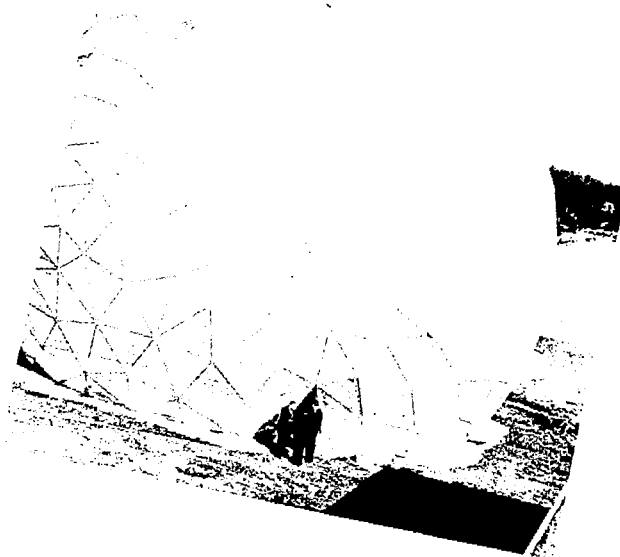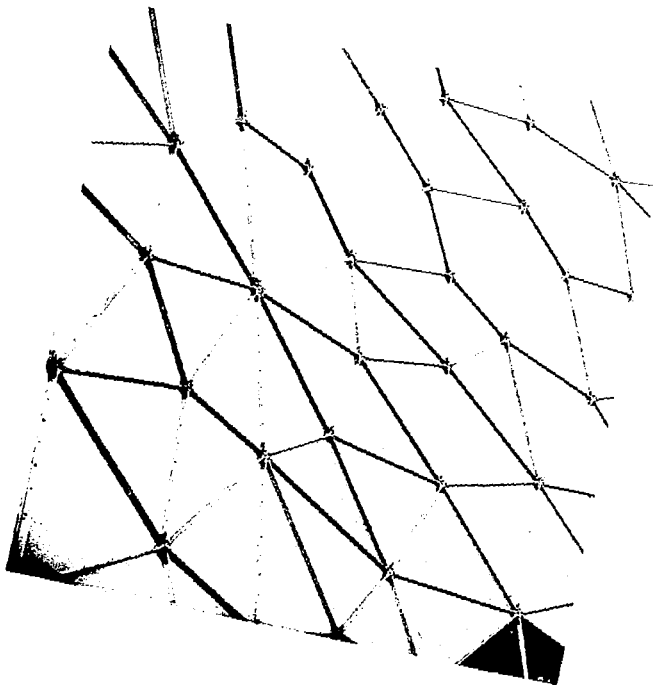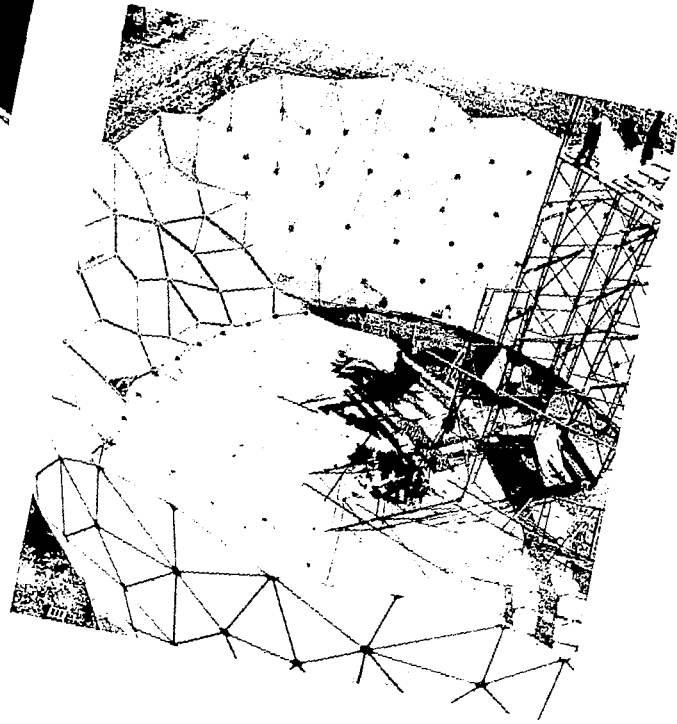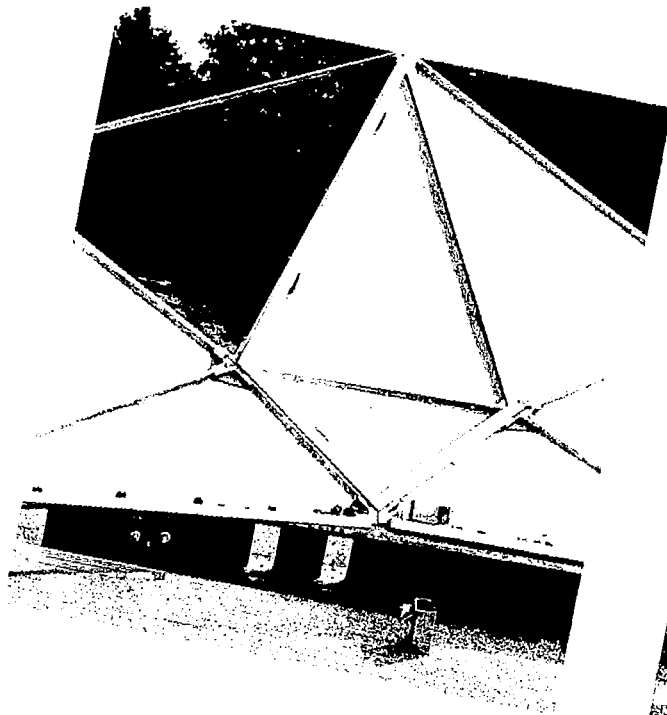
Figure 6-1.   Rigid Radome: Metal Space Frame in Construction
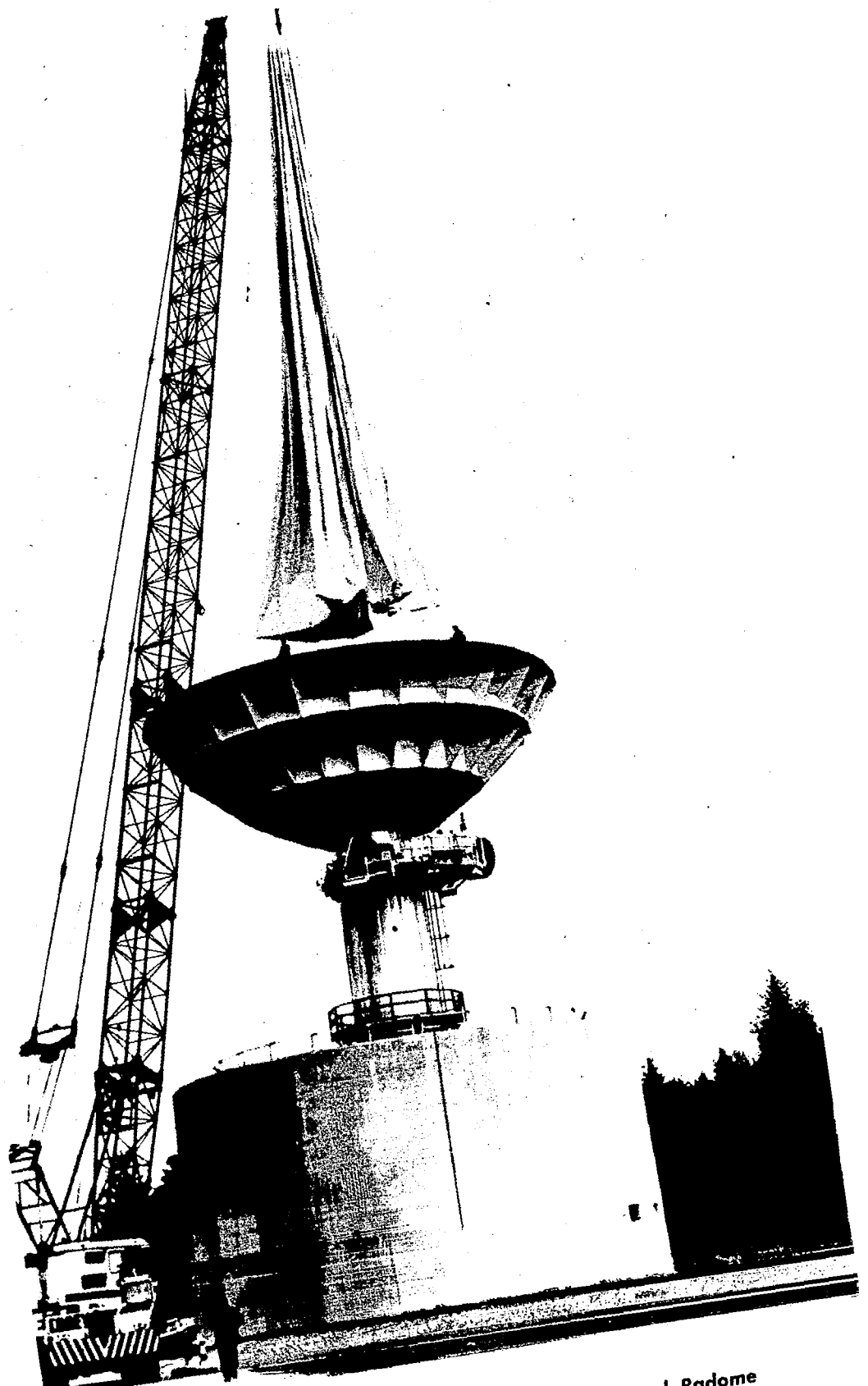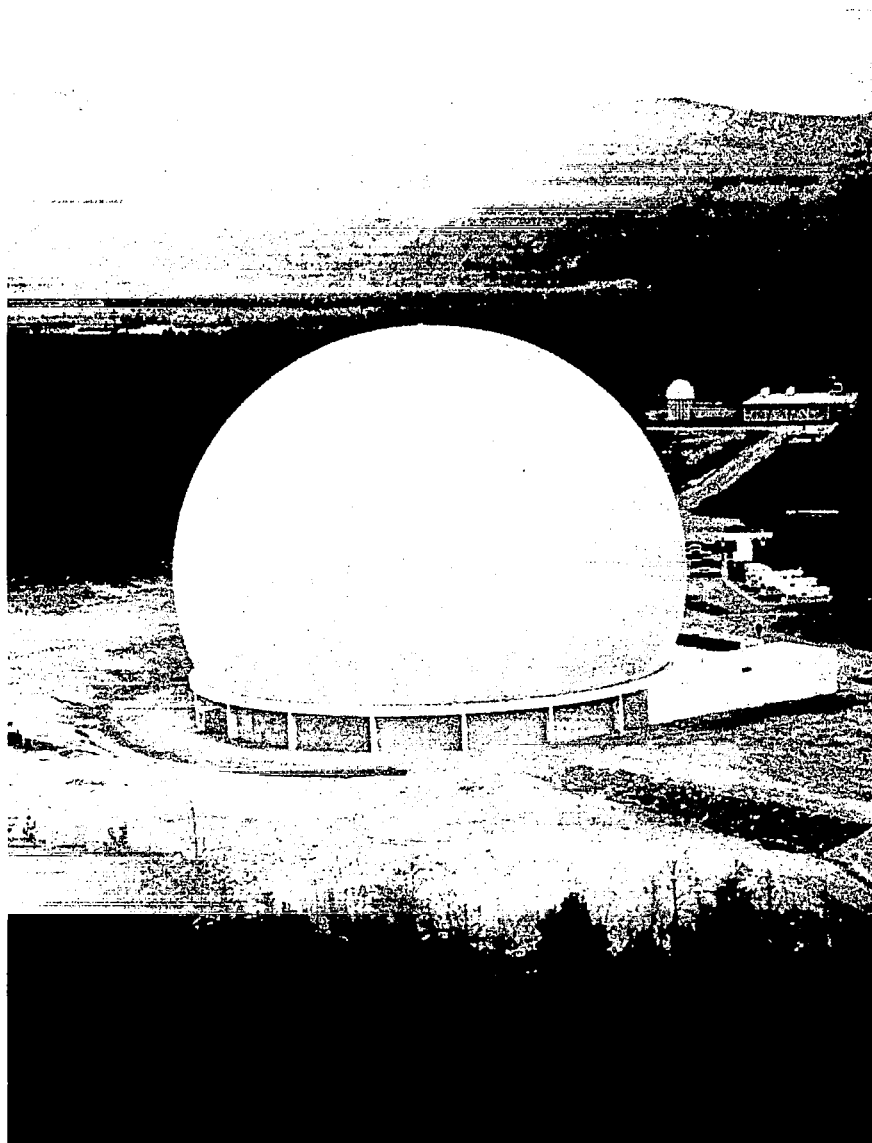
Radome

Figure 6-3. Single-wall, Air-supported Radome
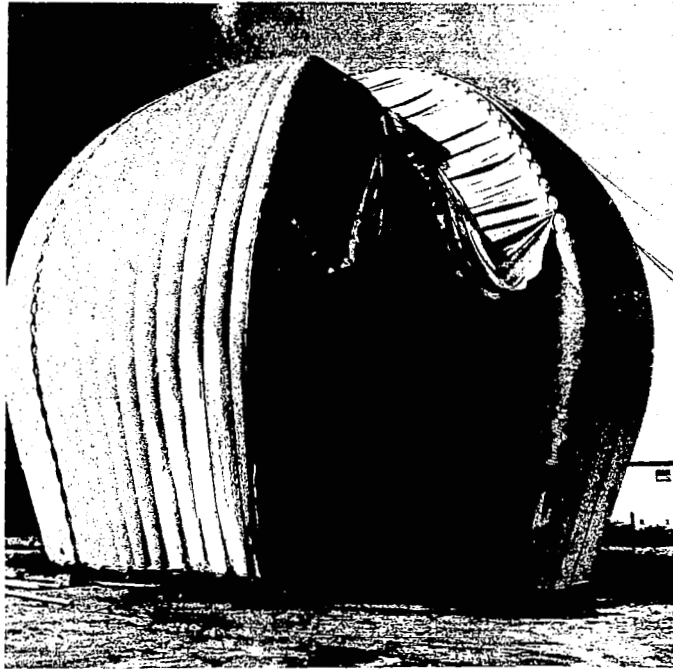
PARTIALLY-INFLATED DUAL WALL (VERTICALLY RIBBED)
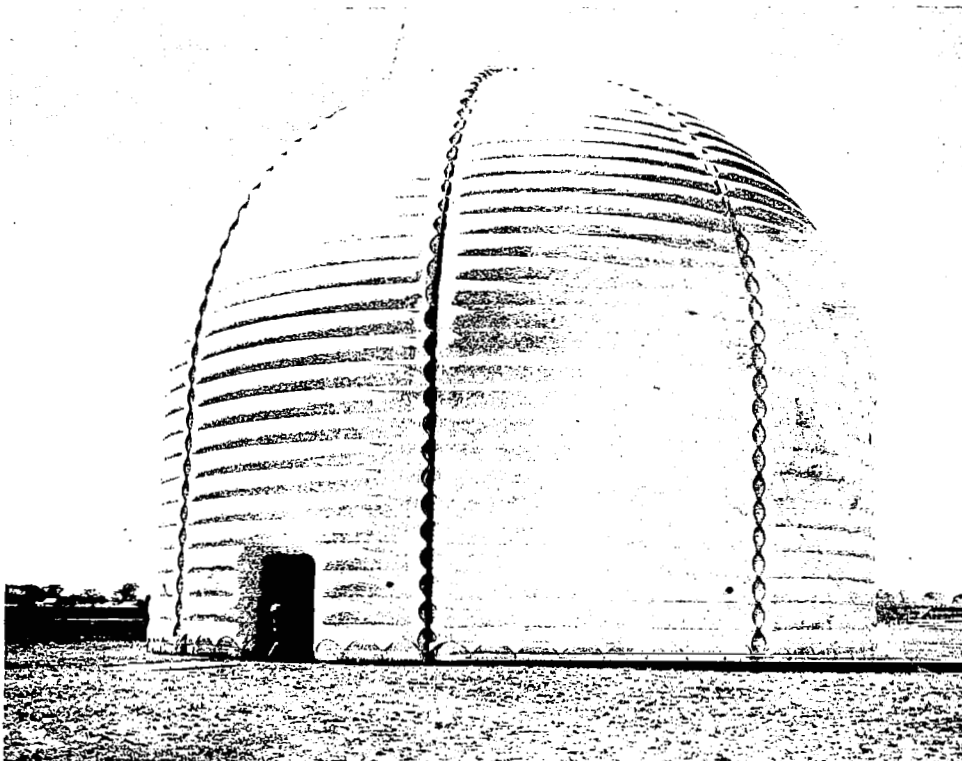
INFLATED DUAL WALL (HORIZONTALLY RIBBED)

Figure 6-4.   Dual-wall, Air-supported Radomes

desirable for frequent access, but some units are built with merely a hatch door.

d. If the sphere should fail in high winds, the material can act as a large sail and may destroy the antenna.

e. Authoritative statements from radome engineers vary greatly on the amount of water the fabric will absorb. Some claim absorption as low as 1 percent of the weight of the fabric; others claim as high as 10 percent. Water absorption by the fabric will increase transmission loss and noise temperature. Noise temperature increases as high as 80°K may be possible when the fabric absorbs around 10 percent of its weight in water.

f. Degradation of antenna sensitivity caused by rain-soaked radomes can persist from 15 to 45 minutes after the rain.

g. The approximate cost in the northeast United States for a 120-foot-diameter single-wall, air-inflatable hypalon dacron radome with complete anchorage and redundant design pressure system is $250,-000.

h. Normal design of single-wall radome is for winds of 100 to 125 mph; however, single-wall inflatable units have been designed for 200 mph winds.

6.4.2 DUAL WALL

a. It is of double-wall construction with individual sections (6 to 8 per radome) supported by entrapped air. The sections are laced together.

b. The sections are erected by inflating with air.

c. The wall construction material, outside to inside is:
(1) Hypalon
(2) Neoprene
(3) Dacron
(4) Neoprene adhesive

d. Double-wall characteristics are as follows:
(1) Excellent thermal insulation by the dead air between the walls
(2) Boresight error estimated at 0.1 + milliradian
(3) Noise temperature increase in dry condition is more than 5° K; increase in wet condition is unknown.
(4) Distinct advantage in handling and transporting because the radome is made in six or eight independent sections.
(5) Erection without cranes and hoists makes it quite feasible for remote locations.

e. Possible use is as a portable shelter for work on 30-foot antennas.

PART B. STUDIES ON THE USE OF RADOMES

Much metal space-frame radome development has taken place at the Lincoln Laboratory of the Massachusetts Institute of Technology. There a radome is being considered to cover the world's largest proposed radio telescope (300 to 500 feet in diameter). The Cambridge Radio Observatory Committee (CAMROC) is estimating the accuracy gain and structural savings for a 450-foot antenna realized by considering the radome at the time of antenna design. Experience has shown that radomes can be over designed, causing electromagnetic wave propagation degradation. A metal space-frame-type radome designed and constructed for the extreme cold winds of the DEW line (200 mph and 70° F below zero) was erected in the Boston area. Because of the heavy structural design for DEW-line weather, the radome had more structural members than necessary, creating a great deal of aperture blockage and resulting in a transmission loss of 1.0 decibel and a 10° K noise temperature rise.

In one Air Force study, reported by H. G. Weiss of the Lincoln Laboratory, involving a 40-foot dish with a radome, the structural savings of the antenna paid for the radome. The cost was the same whether or not the radome was used. Because of the economics of an integrated complex, radomes should be considered along with the original antenna design. Structural savings, radio-wave degradation, and overall programmed life cost should be studied very early in the planning stages of a proposed antenna; it is expensive to put a radome over an existing antenna.

The Communications Satellite Corporation (COMSAT) decided not to use radomes* at any of its ground stations because each 0.1 decibel is significant to its operation. COMSAT uses FM transmission, adjusting the deviations on the sub-

* Several large operational communication satellite ground antennas do have radomes. There are 210-foot-diameter units at Andover, Massachusetts, and in France.

carriers to produce the designed signal-to-noise ratio. Boosting the signal to compensate for circuit losses also means it must increase the deviation of the subcarriers and drop some circuits because the bandwidth of the system limits the number of channels for a given deviation. The fact that increased system sensitivity (even an increase as small as 0.1 decibel) permits more channels to be used governed COMSAT's decision not to use radomes.

The Rohr Corporation study concerned savings in the substructure possible by designing the antenna to be protected by a radome. It illustrated that the economic aspects of radomes for small antennas are questionable because little savings are possible on the substructure. However, the study did point out that for large antennas, 85 feet and larger, there is economic justification for radomes. Protected by a radome, an antenna may be designed with a lower strength requirement as compared to the same antenna designed for use without a radome. As can be readily seen, two items of antenna structure are involved here: the size of the foundation and the framework strength. The engineering savings considerations are only those of initial cost; when lifetime corrosion costs are added, the economic picture for a design with a radome improves even more. It is stressed again that the radome antenna should be designed as a unit to achieve the most favorable economic and structural complex possible.

6.5 RADOME CHARACTERISTICS

The use of a radome means a degradation of radio-wave quality; certain amounts, of course, can be tolerated. The design, power, and mission of the antenna will determine the extent of degradation that is acceptable. When contemplating the use of radomes, consider their characteristics in terms of the overall system performance requirements.

6.5.1 TRANSMISSION AND RECEPTION LOSSES

Attenuation in a radome wall is the result of the cover material or water absorption. Loss varies from 0.05 decibel to several decibels depending on radome construction. Much interesting test work has been done to determine transmission losses on metal space-frame structures paneled with fibrous glass reinforced laminate. Figure 6-5 illustrates the results of the tests. Several
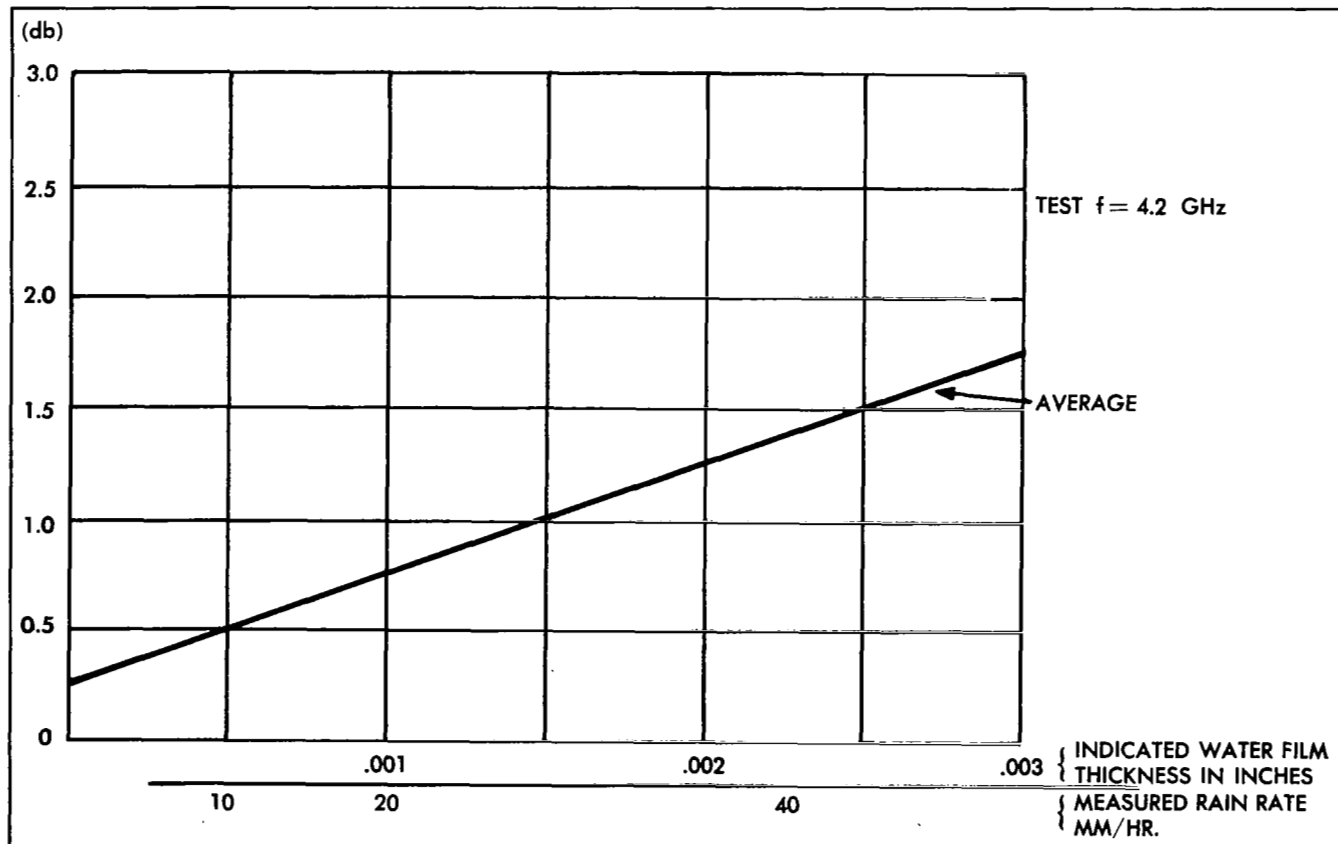
Figure 6-5. *55-foot Metal Space-frame Radome Transmission Loss Caused by Rain*

additional items of interest concerning the tests are:

a. Water absorption by the fibrous glass-reinforced laminate leveled off at approximately 0.5 percent of the material weight.

b. In all tests, the transmitted signal had recovered to within 0.2 decibel of the reference signal level, within 2 minutes of the cessation of the rain.

c. The scale of 40 millimeters of rain per hour is high; rainfall rate of 3 millimeters per hour is likely to be exceeded for only 1 percent of an average year in Washington, D. C.

d. Reflection of energy is caused by the thickness of the radome wall. Thin-wall design reduces this type of loss. Tests have been run to determine the transmission loss resulting from wall thickness and discontinuities resulting from ribs of a space-frame structure. Transmission loss is plotted against frequency for a 55-foot radome and a 125-foot radome in figures 6-6 and 6-7.

e. Reflection or scattering of energy is caused by the discontinuities in the radome. This loss is apparent in radomes that have ribs, flanges, or seams in either the skeleton or the skin.

f. Scatter of energy in thick walls is caused by a nonuniform-phase delay in the incident wavefront.

6.5.2 VARIABLE BORESIGHT ERROR

Boresight error is the angular shift of a beam from its original projection as it passes through the radome material. The beam shift produced by a radome does not remain constant nor does it follow a simple law as the antenna is moved. The beam shift caused by the radome, therefore, must be less than one milliradian. The fact that the error may be constant for any given azimuth and altitude may eventually result in computerized correction of this problem. It has been reported that a major cause of signal jitter or fading may well be winds in excess of 20 knots, especially gusting winds which distort an unprotected antenna. At some point the wind gusts would
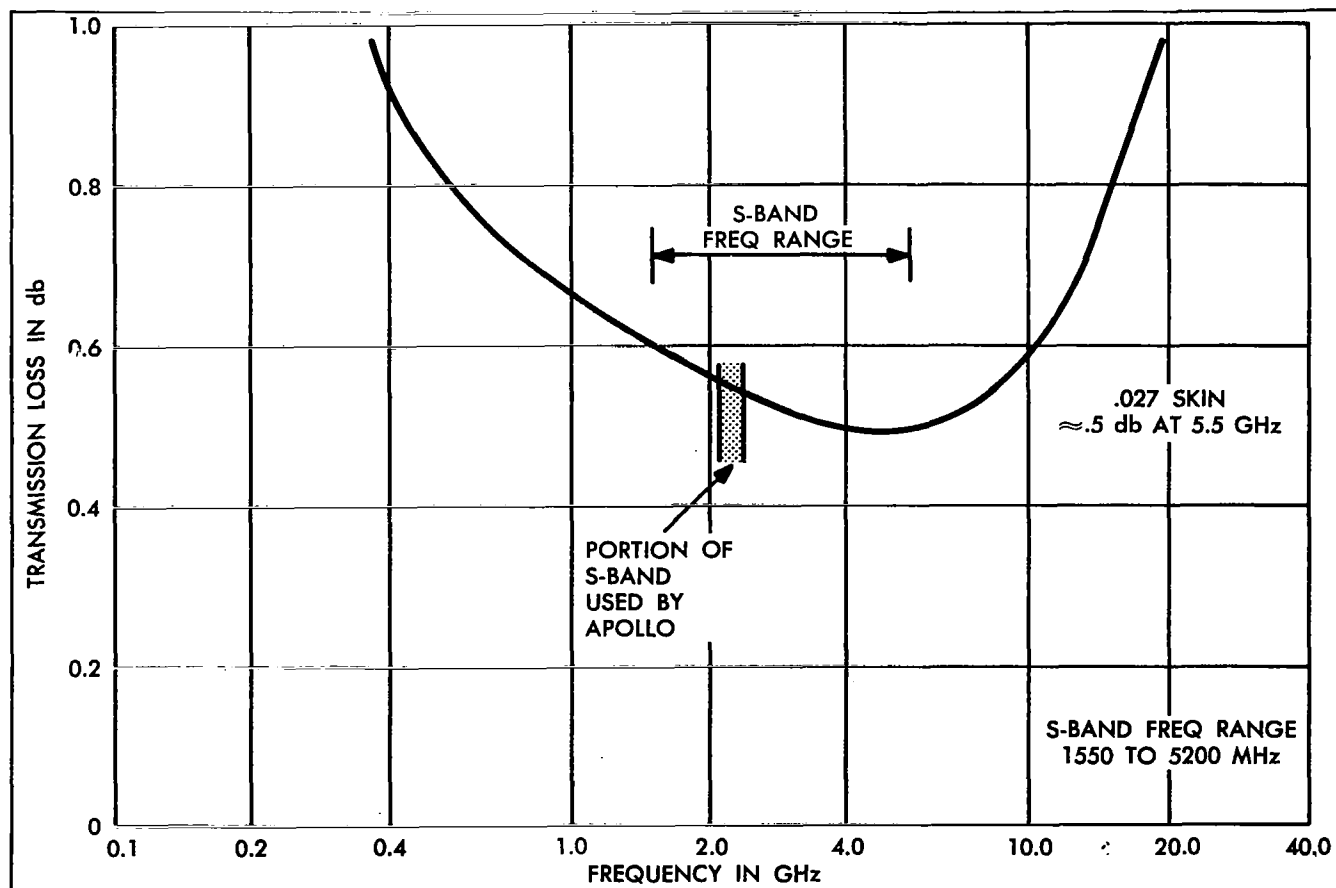
Figure 6-6.   Transmission Loss Vs Frequency, 55-foot Diameter Metal Space Frame (150 MPH Design)
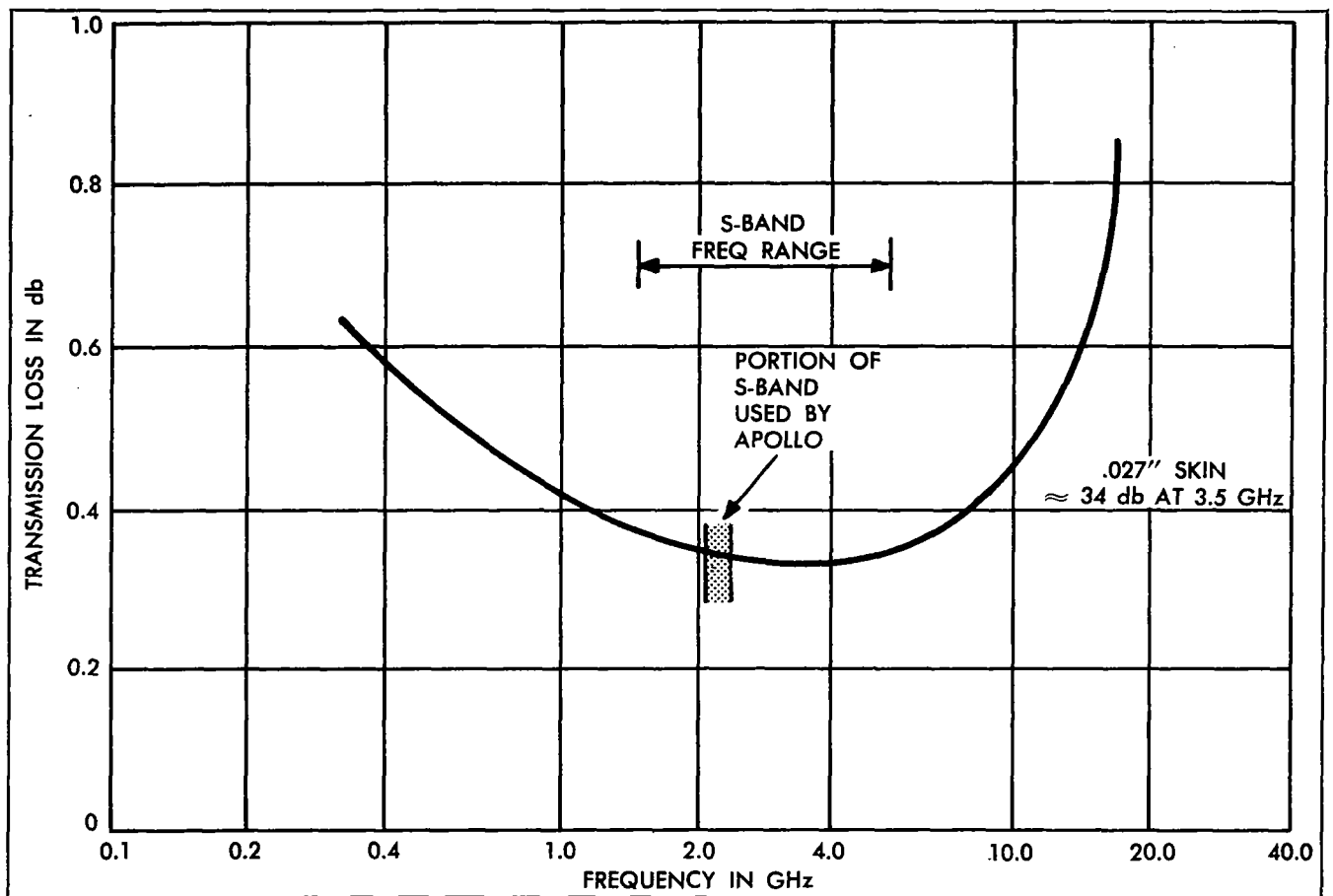
Figure 6-7. *Transmission Loss Vs Frequency, 125-foot Diameter Metal Space Frame (100 MPH Design)*

degrade the mission status more than the bore-sight error.*

6.5.3 EFFECT OF SIDELOBE LEVEL

Sidelobes rob the main beam of transmitting power, resulting in increased noise temperature levels when receiving. Such levels are directly related to the discontinuities in the radome.

6.5.4 EFFECT OF REFLECTIONS

Frequency pulling can occur in a magnetron-type transmitter when direct reflections from the radome wall move into the antenna feed system. Effects are small if a transmitter other than a magnetron is used.

6.5.5 INCREASED NOISE TEMPERATURE

A radome may increase the system noise temperature by causing an increase in sidelobe levels or an increase in dissipated loss in the radome wall material, especially when wet. Calculations of the noise temperature resulting from increased

sidelobe levels are complicated. It means the integration of the contribution of each sidelobe in relation to the temperature that each sidelobe views.

Approximately:

$$T_o = \tfrac{1}{2} (290 + T_s)\,s$$

where: T_o = output temperature increase

T_s = sky temperature

s = fraction of transmitted energy scattered by the radome.

The common method of determining noise temperature resulting from the increased sidelobe levels is a before- and after-installation comparison. Temperature increase for radome dielectric material dissipation loss is calculated as follows:

$$T_o = \frac{290\ (L-1)\ +\ TA}{L}$$

where: TA = antenna temperature

L = power ratio loss of radome material

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* See qualitative plot of wind effect and boresight error, figure 6-8.

The transmission loss caused by the radome dielectric material cannot be measured in the radome because it would include both the sidelobe dissipation and temperature increases. The dissipation loss in present radomes averages about 0.1 decibel except for a wet air-inflated radome.

Specifications by the Electronic Space Structures Corporation for a typical 68-foot diameter metal space-frame radome illustrate the state of the art:

Transmission loss .... 0.5 decibel average
Sidelobe perturbation .... 1.0 decibel
Boresight error .... 0.1 milliradian
Noise temperature increase .. 5° K (at antenna
                          elevation angles above 10°)
Bandwidth .... 800 MHz—11,000 MHz
Wind resistance .... 150 miles per hour
Solar radiation .... 95 percent rejection
Minimum life
    (continuous operation) .... 15 years
Relative humidity .... up to 100 percent

For Military Specifications, refer to:

MIL-R-7705	MIL-E-4158
MIL-R-9300	MIL-P-8013
MIL-P-9400	MIL-R-7575
MIL-P-9503	MIL-P-25421

6.6 THE USE OF RADOMES FOR THE MSFN TRACKING STATION ANTENNAS

Because all radomes degrade the electronic performance of the antenna to some degree, they must be considered as a trade off. In order to gain the advantages offered by a radome, the disadvantages must be endured. The following advantages of integrating the proper radome in the antenna design are quite impressive:

    a. Systems costs, including structural material and support equipment, are lower.

    b. A more precise reflector is possible because of thermal environment control, the absence of winds, and more efficient use of compensating techniques.

    c. The antenna has operational capability at any time.

    d. Maintenance is possible in inclement weather.

    e. Ideal corrosion control is possible in a harsh environment.

The disadvantages have already been listed; therefore, all the information necessary for making a decision has been given. It would appear that if a proper study for a radome for a specific antenna environment demonstrated that the mission could be accomplished at the X level of electronic performance as illustrated on figure 6-8, then everything else is secondary.
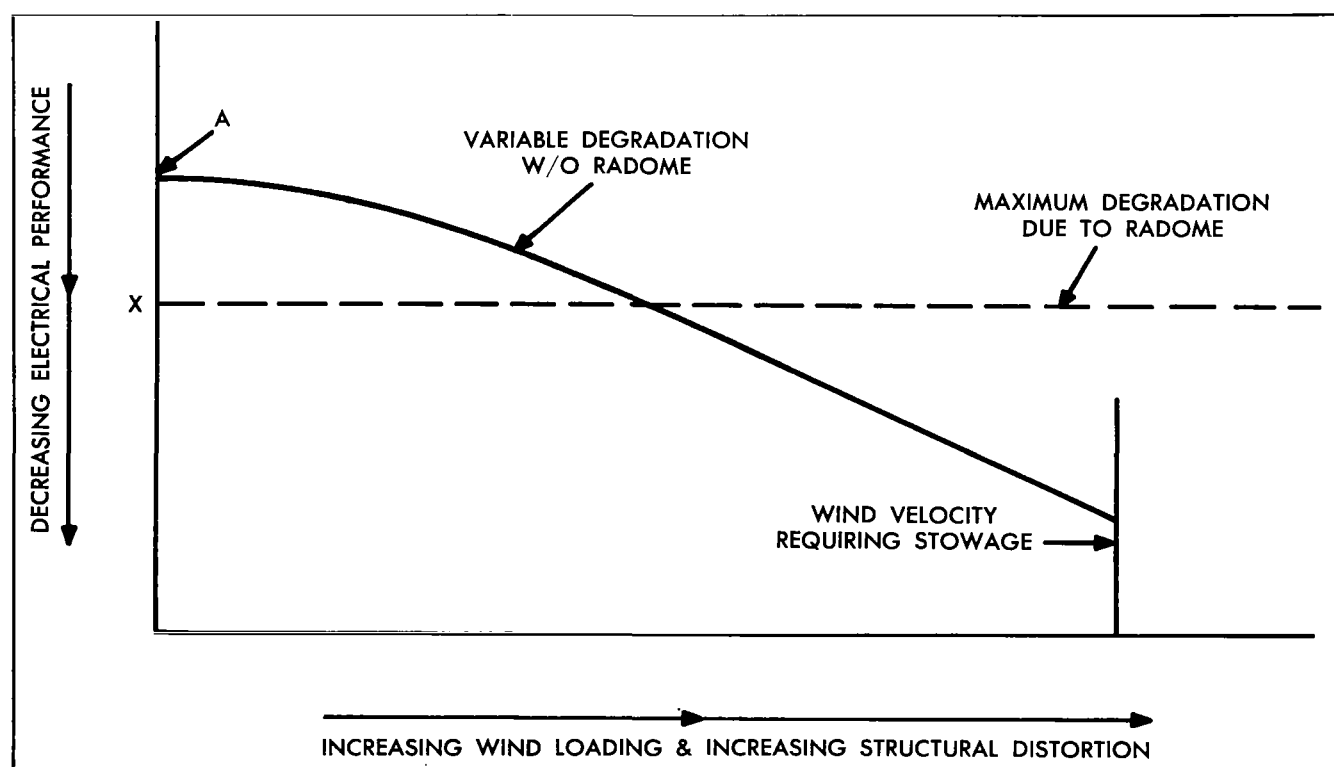
Figure 6-8. *Electrical Degradation Crossover Point for Antenna with and without Radome*

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GLOSSARY OF TERMS

Adhesion:
Chemical attraction of paint to substrate (another paint).

Aeration:
A wind-carried moisture-saline combination. (The 30-foot Apollo dish at Bermuda has 1 to 15 aerations per day, 365 days per year.)

AISI:
American Iron and Steel Institute.

Aliphatic:
Compounds of the general formulas $C_nH_{2n} + 2$, C_nH_{2n} and $C_nH_{2n} - 2$ belonging to a general class known as Aliphatic compounds.

Alkyd:
Any of several synthetic resins made from polybasic acid and polyhydric alcohol, or phthalic anhydride and glycerine.

Amide:
A compound resulting from replacement of an atom of hydrogen in ammonia by an element or radical, or of one or more atoms of hydrogen in ammonia by univalent acid radicals.

Amine:
The ammonia system equivalent of an alcohol; any of a class of compounds derived from ammonia by replacement of hydrogen by one or more univalent hydrocarbon radicals. The characteristic structure of a primary amine is RNH_2; secondary amine, R_2NH; tertiary amine, R_3N. Amines are basic compounds and readily form salts with acids.

Anneal:
Subject to heat and controlled cooling to make a metal mass homogeneous in chemical, crystalline, and mechanical properties.

Antenna gain:
The effectiveness of a directional antenna in a particular direction as compared with a standard dipole antenna, is usually expressed as the ratio of the standard antenna power to the directional antenna power that will produce the same field strength in the desired direction, expressed in db.

Aromatic:
Hydrocarbon compounds of the ring series; the ring structure possesses double bands, making a great number of compounds possible.

ASTM:
American Society for Testing Materials.

Attenuation:
A decrease in signal intensity caused by the absorption and scattering of radio waves in the transmitting medium; an additional cause of attenuation is the divergence of flux caused by distance.

Austenitic stainless steel:
A solid solution of chromium nickel, and carbon or iron carbide in iron; crystalline structure is cubic-faced centered.

Binary alloy:
An alloy composed of two elements, of an element and a radical that acts as an element, or of two such radicals.

Binder (paint):
Primary constituent of the vehicle; cements pigment particles together and fixes the mass to the substrate being coated.

Bonding:
Mechanical attachment of paint to metal.

Boresight error:
A shift from the actual radio frequency axis of the antenna resulting from several factors including the refraction effect of the radome wall.

Butyral:
An acetal of butyraldehyde; a colorless liquid, C_3H_7CHO, made from butyl alcohol and, otherwise, used in making synthetic resins, butyric acid, etc.

Catalyze:
To speed up a chemical reaction by the use of an ingredient (the catalyst) which undergoes no chemical action itself.

Coating system:
The total surface preparation, the application methods and type of paints used on a structure; the programmed life and environment of the antenna should determine the coating system.

Conversion coating: Surface film formed by a reaction in which a portion of the base metal is converted to one of the components of the film.

Decibel (db):   This unit is used to express power ratio, db $= 10 \log P_1/P_2$ where P_1 and P_2 are the two powers being compared. For example, 3 db down (-3 db) means a loss of 50 percent power. Do not confuse with the decibel for measuring the volume of a sound, which is equal to the logarithm of the ratio of intensity of the sound to the intensity of an arbitrarily chosen standard.

Detergent: With water, wets metal surface and forces dirt off.

Dielectric constant: The ratio of the dielectric quality of a material to the dielectric quality of air, the dielectric quality of air is one.

Emulsifying agent: Suspends the dirt, prevents redeposition.

Electrolyte: A substance which may be disassociated into ions or ionize in solution; electrolytes conduct electricity.

Electrolytic cell: A cell which converts electrical energy to chemical energy.

Environment: As applied to antennas, this includes all the effects of weather, the land, the sea, and pollutants of man that tend to corrode structures.

Epoxy: Epoxy resin used in the epoxy base is a form of plastic derived from petroleum. In the form of paint, the epoxy base is mixed with a catalyst or converter; the chemical reaction is polymerization.

Eutectic: An alloy with the lowest melting point possible from a combination of the same components.

Ferric hydroxide: $Fe(OH)_3$

Ferric ion: Fe^{+++}

Ferric oxide: Fe_2O_3

Ferritic Steels: A solid solution of chromium and carbon and iron carbides in iron; crystalline structure is body-centered cubic.

Ferrous hydroxide: $Fe(OH)_2$

Ferrous ion: Fe^{++}

Ferrous oxide: FeO

FM: Frequency modulation; modulation of a sinewave carrier so that its instantaneous frequency differs from the carrier frequency by an amount proportionate to the instantaneous amplitude of the modulating wave.

Frequency data: Hertz = Hz = Cycles per second
1 Mc = 1 MHz
1 Gc = 1000 Mc = 1000 MHz
'L' Band from 390 to 1550 MHz
'S' Band from 1550 to 5200 MHz
'C' Band from 5000 to 6500 MHz
'X' Band from 5200 to 10,900 MHz
Microwave frequency: approximately 1000 MHz to 100,000 MHz
(1 GHz to 100 GHz)
Wavelength/frequency formula: $C = f \times \lambda$
3×10^8 meters per sec $= \lambda \times f$
Where:
C = velocity
λ = wavelength
f = frequency

Galvanic couple:	A closed electric circuit of two connected dissimilar metals joined by an electrolyte.
Huey test:	A laboratory test subjecting samples of stainless steel to boiling 65 percent nitric acid to check for ~~transgranular and~~ intergranular corrosion.
Inorganic:	Not derived from animal or vegetable life, no CH radical in the molecule.
Kelvin scale:	A scale of temperature measured in degrees centigrade from absolute zero.
Ketones:	Powerful solvents, acetones.
Long-oil alkyd:	Approximately 60 gallons of linseed oil per 100 pounds of resin, very flexible.
Magnetron:	An electron tube using an electromagnet to control the flow of electrons from cathode to anode.
Martensitic steel:	A solid solution of chromium and carbon or iron carbides in iron; crystalline structure is body-centered tetragonal.
Medium-oil alkyd:	Approximately 30 gallons of linseed oil per 100 pounds of resin, moderately flexible.
Megacycle:	One million cycles (recently changed to one megahertz, MHz).
Microwave:	Radio transmission using a very short wavelength (20 centimeters or less); Apollo antennas use an uplink frequency of approximately 2100 megahertz and a wavelength of approximately 14 centimeters and a downlink frequency of approximately 2287 megahertz and approximately 13 centimeters in wavelength; both are in the microwave S-band.
MIL:	Military abbreviation; usually used to denote a military specification, for example, MIL-P-15328B.
Milliradian:	One thousandth part of a radian; a radian equals approximately 57.29 degrees.
Natural frequency:	The mechanical resonance of the antenna structure.
Noise:	Unwanted energy (or the voltage produced), usually of random character, present in a transmission system, and resulting from many causes.
Noise temperature:	This is the measure of noise in a network or system expressed in degrees Kelvin. This method of measurement is based upon a comparison of the noise being measured with the noise produced by a perfect receiver operated at a temperature of 290° K. A perfect receiver would produce no noise at 0° K where no thermal agitation of electrons occurs.
Nonuniform phase delay:	Unequal time delays of portions of the incident wave fronts caused by unequal distances through the wall material traversed by those portions of the beam because of the angle of their incidence with the radome wall.
Oils:	Usually pertaining to linseed, soya, castor, or fung oil used as a binder in paints.
Organic:	Relating to or containing carbon compounds.
Oxidation:	A loss of electrons.
Oxidizing agent:	A substance that can accept electrons.
Paint:	Fluid-like substance usually consisting of a pigmented filler, a binder, and a thinner.
Paint life:	The time required for a new coating system to reach a point where 1 percent of the total protecting coating system has broken down.
Paint system:	See Coating system.
Passivate:	To make more resistant to corrosion, usually a natural action by which a protective oxide film is formed over the metal.

Passivation:

Retardation of corrosion by the formation of a surface film; the nature of this is not yet completely understood. This definition implies an active to passive transition which is generally accompanied by a large reduction in the corrosion rate. Iron, chromium, nickel, titanium, and alloys based on these important construction metals in addition to several other metals and alloys of lesser interest are capable of undergoing the active-passive transition.

Phenol:

White crystalline compound, C_6H_5OH, produced from coal tar; makes an excellent resin or binder.

Phthalic anhydride:

A white solid substance, $CH(CO_2)O$, produced by the oxidation of naphthalene and used to make synthetic resin.

Pigment (paint):

Usually this is an insoluble powder carrying the coloring matter. Some pigments are acid sensitive and some are alkali sensitive. A lead pigment is unsuited to a sulfur atmosphere. Certain titanium pigments catalyze the photochemical decomposition of the binder and produce chalking.

pH:

Hydrogen-ion concentration, the relationship between pH and hydrogen-ion concentration follows:

H-ion Concentration		pH
1.0	(0.0)	0.0
.0000001	(10^{-7})	7.0
.0000000001	(10^{-10})	10.0

pH is a logarithmic function; therefore, a solution having a pH of 6.0 has 10 times as many hydrogen ions as a solution having a pH of 7.0 which is a neutral solution.

Polarization:

This is a decrease in differential between the anode and cathode voltages resulting in a reduced corrosion rate. These voltages tend to approach a common value as corrosion products surround either the anode or the cathode or both. The cathode usually polarizes to a greater degree than the anode, and the tendency to polarize varies greatly among metals, electrolytes, etc., (resistance to the flow of current at the metal-liquid interface).

Polyamide:
~~Polyamide~~:

A compound characterized by more than one amide group.

Polymerization:

This is the chemical reaction between the epoxy base and converter. The film formed by the polymerization is chemically tied up or cross linked, giving great durability and chemical resistance to the coating. Conventional paint does not polymerize and dries by evaporation or oxidation.

Polymerize:

To combine similar molecules forming another compound having a higher molecular weight and different physical properties than either of the constituents.

Polyvinyl:

A synthetic resin, divided into two general types: polyvinyl chloride and polyvinyl acetate.

Post cure:

A coating followed later by the application of a curing solution to speed up the drying process; the drying time is approximately 24 hours.

Precipitation hardening:

The hardening of a metal resulting from the addition of a proper alloying element.

Reducing agent:

A substance which can lose electrons.

Reduction:

Gain of electrons.

Resin:

Any of the various solid or semisolid organic substances exuded from various plants and trees or prepared synthetically; resins are soluble in ether or alcohol.

Saline aeration:

A fog, mist, or condensation carrying ionized salts from the ocean.

Sapon:	A prefix of soap or similar to a soap.
Saponifying agents:	Renders certain dirts water soluble by chemical action.
Saponifying paints:	The formation of soap in paint film resulting from the reaction of a fatty acid ester with an alkali.
Self-cure:	All of the curing elements are combined in the coating material when it is applied. The drying time may be from 72 hours to 3 weeks.
Sensitization:	Rendering less corrosion resistant or nonpassive; when austenitic stainless steels in the solution-quenched condition are reheated to 650°—1500° F, chromium carbides precipitate at the grain boundaries, depleting them of chromium, lowering their corrosion resistance, and providing paths for corrosion.
Short-oil alkyd:	Ten gallons of linseed oil per 100 pounds of resin, very inflexible.
Side lobe:	A portion of the beam from an antenna other than the main lobe and usually much smaller.
Sky temperature:	The intensity of cosmic radio emissions expressed in degrees Kelvin.
Solid solution:	Other elements dissolved in the crystal.
Solvent (paint):	Keeps the binder dissolved to permit application of paint after which solvent dries up (also known as the thinner or volatile vehicle).
SSPC:	Steel Structures Paint Council, Carnegie-Mellon University, Pittsburgh, Pa.
Stabilization:	In austenitic stainless steels, this is preventing corrosion susceptibility caused by chromium depletion. Several methods can be employed, including: 1. A high-temperature heat treatment to place all of the chromium in solid solution, followed by a rapid water quenching to prevent carbide precipitation. 2. Addition of strong carbide forming elements to the alloy, such as Ti or Cb, to prevent formation of chromium carbides. 3. Lowering of the carbon content to below 0.03 percent to minimize formation of chromium carbides.
Subcarrier:	A carrier wave used to modulate another carrier wave.
Surface preparation:	The degree to which the surface to be painted is prepared to receive the coating; there are four classes of surface preparation for metals.
TT:	This is a prefix designating a Federal Government Specification, for example, TT-P-636C. Many of the TT specifications are converted military specifications.
Urethane:	A white crystalline compound, $C_3H_7O_2N$, produced by the action of ammonia on ethyl carbonate or by heating urea nitrate and ethyl alcohol.
Vehicle (paint):	A fluid consisting of a solution of a binder mixed with a thinner (solvent).
Vinyl:	Synthetic resin binder, a monovalent radical, CH_2CH, characteristic of many derivatives of ethylene, its hydride.
Vinyl resin:	A vinyl polymer.
Wetting power:	Penetrating power of the paint binder, soaks into dirt and rust of surfaces that are impractical to clean to white or near-white condition, wetting power is determined by the percentage of oils and thinners in the binder.
Yield strength for magnesium:	The stress at which the stress-strain curve deviates 0.2 percent from the modulus line.
Yield strength for steel:	That stress at which the first permanent deformation takes place, or beyond the point of complete recovery.

Cast Aluminum Alloy Designations

In February 1970, the Aluminum Association adopted a new system to designate cast aluminums. It will replace the one on page 3-2 as usage, and experience accumulate.

Aluminum Association Cast Aluminum Alloy Designations

February 1970

1 XX.X .... 99% + pure Al

2 XX.X .... Al - Cu

3 XX.X .... Al - Si
Plus Cu and/or Mg

4 XX.X .... Al - Si

5 XX.X .... Al - Si

6 XX.X .... Unused at present

7 XX.X .... Al - Zn

8 XX.X .... Al - Sn

9 XX.X .... Other major alloying
elements

G-6

INDEX

Page